Arizona Department of Transportation
Intermodal Transportation Division
206 South Seventeenth Avenue Phoenix, Arizona 85007-3213

ADOT

Janet Napolitano
Governor

Victor M. Mendez
Director

Michael J. Ortega
State Engineer

December 28, 2004

Mr. Robert Hollis
Arizona Division Administrator
Federal Highway Administration
One Arizona Center, #410
400 East Van Buren Street
Phoenix, Arizona 85004

Dear Mr. Hollis:

This letter transmits the first report completed by the Arizona Department of Transportation (ADOT) for the Quiet Pavement Pilot Program (QPPP). The report, titled QPPP Progress Report No. 1, summarizes program activities completed through the end of November 2004. Progress Report No. 1 includes noise data collected on or near freeway segments overlaid with asphalt rubber friction course (ARFC) for Construction Phases I and II.

Future progress reports will be completed as program milestones occur and at least one progress report will be completed each calendar year. ADOT anticipates completing Progress Report No. 2 in mid-2005.

Sincerely,

Michael Ortega
State Engineer

Copies: Robert Armstrong, FHWA
Bill Vachon, FHWA
Ken Davis, FHWA
Steve Thomas, FHWA
Mark Swanlund, FHWA
Dr. Judy Rochat, US DOT Volpe Center
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Perry Powell, ADOT PCD
John Hauskins, ADOT PMD
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Greg Wold, HDR
Emily Paulsen, HDR
Mike Dennis, ADOT EEG

Progress Report No. 1
Quiet Pavement Pilot Program
December 23, 2004

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I. Introduction

This report summarizes activities completed to date on the Quiet Pavement Pilot Program (QPPP), a research program partnering the Federal Highway Administration (FHWA) and the Arizona Department of Transportation (ADOT). ADOT initiated the QPPP in April of 2003 after approval by FHWA (**Appendix 1**).

The QPPP consists of two components: construction and research. The construction component consists of overlaying approximately 115 miles of existing urban freeways with asphalt rubber friction course (ARFC) in five separate phases. The research component evaluates the potential for using ARFC as a noise mitigation measure. A map of the Maricopa County Regional Freeway System is included as **Appendix 2**.

Overview
The research component of the QPPP consists of three separate technical studies designated as Site I, Site II, and Site III. The studies at the three types of study sites, located on or adjacent to selected Maricopa County Regional Freeways, involve measuring traffic noise levels prior to applying ARFC (hereinafter referred to as *Before* measurements) and measuring traffic noise levels at the same monitoring locations subsequent to the application of ARFC (hereinafter referred to as *After* measurements). Site I examines freeway noise reduction at the tire pavement interface due to the application of ARFC. Site II examines noise reduction in urban residential neighborhoods associated with the application of ARFC to a nearby freeway segment. Site III studies the combined effect of local weather conditions, distance, and height on freeway noise reductions associated with the application of ARFC and will evaluate the relationship between near-field and far-field noise measurements.

Stakeholders
ADOT's Arizona Transportation Research Center (ATRC) manages research project activities for Site I and Site III. The Noise Team of ADOT's Environmental and Enhancement Group (EEG) manages research project activities for Site II. The State Engineer's Office provides overall project management (both the construction and research components) for ADOT. The Maricopa Association of Governments (MAG) participated in preliminary project planning and provided the majority of funding. Progress reports and research study results are submitted to FHWA.

Brief History
ADOT first used asphalt rubber products in 1964 and increased the use of asphalt rubber products in 1968. ADOT developed a two-layer, asphalt-rubber overlay system for Portland cement concrete pavement (PCCP) in 1973. ADOT replaced the two-layer system with a three-layer system in 1975 and the first non-experimental section was placed on I-17 in Phoenix in 1985 as part of a pavement preservation project. ADOT eventually replaced the three-layer system with a single-layer, open-graded system, one-inch in thickness. ADOT overlaid a 1.5-mile section of southbound I-19 near Tucson, Arizona in 1988 with a one-inch layer of ARFC; portions of this overlay are still in service today. The one-inch thick ARFC surfacing currently used by ADOT consists of a 3/8" minus, open-graded aggregate mixed with asphalt-rubber binder that ranges from 9.0% to 9.6% by total mix weight. This ARFC mix design has been used for most of the PCCP overlay placements since 1988.

Freeway expansion projects on I-17 and US 60 (Phoenix metropolitan area, late 1990s) helped initiate the QPPP. Both projects involved adding travel lanes and HOV lanes to the two existing, heavily traveled freeways. Instead of replacing aging PCCP with new PCCP, ADOT decided to overlay existing sections and newly constructed sections with ARFC. Although the intent was to reduce the cost and duration of construction, residents near the expanded freeways praised the overall reduction in traffic noise.

Consequently, ADOT constructed a 1-mile test section of ARFC on SR 101 near 90th Street in Scottsdale, Arizona in the fall of 2002. The purpose of this test section was to demonstrate the effectiveness of using ARFC as a noise mitigation strategy. The noise study technical report by Higgins & Associates summarizing this initial ARFC test section is included as **Appendix 3**.

FHWA approved ADOT's request to study pavement surface type as a potential noise mitigation strategy in April of 2003. FHWA approval was based on the results of the ARFC network evaluation, the PCCP noise characteristics study, and a large body of research provided by the California Department of Transportation (Caltrans). Since ADOT and Caltrans collaborated on the issue of pavement noise in the past, the two agencies collectively approached FHWA to establish the Quiet Pavement Pilot Program.

ADOT initiated Phase I paving operations in August of 2003, which were completed in November of 2003. Phase II paving operations were completed in June of 2004. Phase III paving operations were completed in November 2004, except for the eastbound lanes of SR 202 from 20th Street to 32nd Street and the westbound lanes of I-10 from Warner Road to Baseline Road in Phoenix, Arizona. These segments will be overlaid with ARFC in the Spring of 2005 to comply with the construction specification for ambient temperature of existing pavement.

Much of the forgoing history was summarized from the report *"Development of Arizona's Quiet Pavement Research Program"* by Larry Scofield of ADOT's ATRC and

Paul Donavan of Illingworth & Rodkin. Please refer to the report included as **Appendix 4** for a more detailed history of the QPPP.

II. Program Description

ADOT requested formal approval of the Quiet Pavement Pilot Program from FHWA in April of 2003. The request letter included Attachment 5, which consisted of a detailed program description and work plan to manage the research. The ADOT letter requests approval to initiate a pilot study to evaluate the effectiveness of quiet pavement as a noise mitigation strategy. The pilot study will provide research level methodology to identify, evaluate, and document the effectiveness of rubberized asphaltic friction course, and possibly other pavements, as quiet pavement technology to reduce traffic noise on sections of the Regional Freeway System in Maricopa County. The request letter and attachment are presented as **Appendix 1**.

A provision of the QPPP agreement allows ADOT to use a 4 dBA noise reduction when considering projected traffic noise impacts or designing noise barriers for transportation projects proposed on selected QPPP freeway segments. The combination of proposed barriers and the application of the 4 dBA noise reduction must result in at least a 5 dBA overall reduction in projected noise levels. Applying the 4 dBA reduction may eliminate some noise barriers or may result in noise barriers with decreased heights. However, the agreement stipulates transportation projects approved for the 4 dBA credit consideration must be designed so noise barriers can be added or existing barriers can be increased in height, if research data (collected during the research study to validate the sustained noise reduction capabilities of ARFC overlay) indicates noise reduction associated with ARFC is not sustained. ADOT designs and constructs selected transportation projects so noise barriers can be added or existing barriers can be modified after completion to accommodate increased heights.

ADOT applied the 4 dBA noise reduction credit to transportation projects proposed for SR 202. Specifically, the 4 dBA noise reduction credit was applied to noise barriers proposed for the Red Mountain Freeway from University Drive to Southern Avenue and for the Superstition Freeway/Red Mountain Freeway/Santan Freeway Traffic Interchange (Super Red Tan TI). Other noise "hot spots" near QPPP freeway segments may incorporate the 4 dBA noise reduction credit if noise barriers are designed for future transportation projects on selected QPPP segments.

ADOT encourages input from benefited residents living in impacted neighborhoods adjacent to freeway segments where the 4 dBA noise reduction credit was applied to proposed noise barrier design. ADOT allows benefited residents to vote on proposed barrier heights from the perspective of visual impact. The benefited residents are offered a choice between barriers designed without the 4 dBA noise reduction credit (increased height) and barriers designed with the 4 dBA noise reduction credit (decreased height). Using the public involvement process, ADOT conducts a public meeting where the different barrier height options are presented and votes of the benefited residents are tabulated. ADOT promotes participation in the voting procedure through public announcements, telephone interviews, door-to-door flyer distribution, and in-person interviews.

Research methodologies and results for each site are discussed in the following sections. Please refer to Attachment 5 in **Appendix 1** for additional descriptions of the research program and data acquisition methodologies. Data and figures for the different study sites are included in the appendices.

III. Site I

Description

Site I considers noise data acquisition as a typical ADOT pavement management system (PMS) data collection activity. ADOT normally collects pavement attributes in the travel lane at every milepost. A new pavement parameter, noise reduction, was added as a PMS collection activity for the QPPP. Noise reduction data consists of collecting *Before* and *After* noise measurements at the tire/pavement interface at every milepost within the program limits. Noise reduction data was collected using a close proximity (CPX) trailer. Air and pavement temperatures were recorded simultaneous to collecting each near-field noise reduction measurement. *Before* and *After* noise measurements were collected in both travel directions on freeway segments receiving ARFC overlay.

Other ARFC pavement parameters will be discussed in a future QPPP progress report. Site I smoothness data and skid resistance have been measured but not evaluated.

The current Site I data has not been corrected for temperature. A future QPPP progress report will evaluate the validity of applying a temperature correction as reported by Sandberg.

ADOT currently is comparing the Site III, five-minute Leq acoustic data and the environmental data. The results of the evaluation will be discussed in a future QPPP progress report.

Site I noise reduction data will be collected bi-annually after the initial *Before* and *After* near-field measurements. The purpose of the bi-annual measurements will be to evaluate sustainability of noise reductions over the life of the ARFC overlay and to evaluate seasonal effects.

The noise reduction data collected at the tire/pavement interface are defined as near-field measurements. All other noise measurements discussed relative to the remaining study sites are defined as far-field measurements.

Field Activities

Noise reduction data was collected using a close proximity (CPX) trailer. Air and pavement temperatures were recorded simultaneous to collecting each near-field noise reduction measurement. Site one testing consisted of obtaining a five-second sound spectrum at each milepost location in the travel lane. A one-third octave analysis of the spectrum was performed. The acoustical data was collected using a towable trailer constructed to the ISO standards for CPX testing. Testing was conducted at 60 MPH using both a Goodyear Aqua Tread III tire and a Uniroyal Tiger Paw tire. Results reported in this progress report pertain only to the Goodyear Aqua Tread III tire.

ARFC smoothness data and skid resistance has been collected but not reviewed. These ARFC pavement parameters will be discussed in future progress reports.

Results

The ARFC overlay consistently reduced tire/pavement noise at all Site I locations. Reductions ranged from 7 to 10 dBA. The Site I data results are shown in **Appendix 5**. The Figure titled "Comparison of ARFC Overlay Effectiveness" graphically presents the overall averages of the *Before* and *After* measurements for the CPX testing using the Goodyear Aqua Tread III tire. The approximate age of each ARFC application is also shown. It should be noted that the US 60 and I-17 corridors were constructed prior to approval of the QPPP and do not have *Before* measurements. Both of these routes had widened transverse joints so their inclusion with the QPPP program is questionable, but they were included as an attempt to evaluate the effect of pavement age on continued noise reduction. The eastbound lanes of the I-10 segment received ARFC overlay during the current Phase III construction activities and *After* measurements could not be completed in time for inclusion in this QPPP Progress Report No. 1.

The remaining graphical plots indicate tire/pavement noise measurements at each milepost for the designated route. As noted on the plots, the post overlay variability is less than the pre-overlay conditions. This data does not include a temperature correction. The most current data, measured November 4, 2004, exhibited higher values than expected. A second round of testing has been scheduled to verify these measurements. Sound intensity will be measured as part of the verification process.

Study Methodology Refinements

Two issues relating to Site I and Site III study methodologies have arisen. The two issues and proposed solutions are presented below

Traffic classification: Two forms of traffic classification systems have been used, a radar-based system and a video-based system. The radar-based system has been determined to lack accuracy for research grade activities and has been discontinued. The approach used to videotape the traffic proved inadequate to collect data lane by lane. For future work, a new video camera system and receiver hitch based pole support will be purchased and utilized. The previous approach did not mount the camera high enough or at the correct angle for lane distributions. This will be corrected.

Vehicle Speed Determination: Vehicle speed was determined using three different techniques: global radar, hand held radar gun, and video reduction. The global radar approach has proven inadequate and will no longer be used. The video reduction also seems suspect at this time. In the future there will be some small scale studies to use probe vehicles and hand held radar guns to determine if the excessive speeds reported are actual or artifacts of the measurement system. In addition, there will be a third study to validate the hand held radar gun effectiveness.

IV. Site II

Description

Site II data acquisition involves collecting *Before* and *After* noise measurements in residential neighborhoods adjacent to urban freeways overlaid with ARFC. Monitoring locations were chosen to represent typical urban subdivisions because the purpose of the Site II study is to evaluate noise reductions in residential neighborhoods due to the application of ARFC overlays on the freeways. In addition, noise measurements were collected when freeway noise was anticipated to be loudest: Level of Service (LOS) C, defined as maximum traffic volume traveling at posted speeds; time of day when peak traffic volumes occur; maximum traffic volume days (Tuesday, Wednesday, or Thursday) and clear, calm weather.

Each monitoring location will be modeled for pre-overlay conditions (PCCP) and post-overlay conditions (asphalt concrete, referred to as AC) using the new FHWA approved Traffic Noise Model (TNM), Version 2.5, and the appropriate pavement surface setting (PCCP or AC). The purpose of modeling will be to evaluate monitoring locations that exhibit unusual noise level reductions.

Each Site II monitoring location will have a minimum of two modeled noise values (*Before* and *After* conditions) and four ambient measurements (*Before*, *After*, and two bi-annual measurements) as the QPPP research efforts continue. Initial bi-annual noise measurements will be collected in the Spring and Fall around the two-year threshold of the *After* measurement. Where possible, Site II bi-annual noise measurements will coincide with Site I and Site III monitoring. The purpose of the bi-annual measurements will be to evaluate sustainability of noise reductions over the life of the ARFC overlay.

HDR Inc. manages Site II research activities for ADOT. Their technical report summarizing Site II milestones will be included in an upcoming progress report.

Field Activities

Times of daily peak freeway noise levels were determined for each freeway segment by monitoring traffic noise levels for 24 hours to establish the morning and evening peak noise levels. Three noise measurements were recorded at each neighborhood location during daily times of peak traffic noise using a 20-minute monitoring period. When three noise measurements agreed within 3 decibels, noise monitoring was terminated and the three measurements were averaged to provide a single noise level for the monitoring location. Traffic volumes for the monitoring period were determined by simultaneously recording traffic on videotape, then counting vehicle number and types in the office. Noise measurements presented in the data table were adjusted for traffic volume.

Air temperature, humidity, wind speed, and wind direction were recorded simultaneously with the noise measurement using field meteorological instruments. Each monitoring site was sketched on the field data form and digitally photographed. Pertinent characteristics of each site were also recorded on the field data form.

Results

The ARFC overlay reduced freeway noise at all Site II locations measured to date. The average noise reduction was 4.9 dBA for all 40 measurements and noise reductions ranged from 0.1 dBA to 9.8 dBA. Noise reductions at 16 of the 40 Site II locations were less than 4.0 dBA, which represents 40 percent of the locations. **Appendix 6** presents tables of *Before* and *After* measurements and includes traffic data, weather conditions, and monitoring site characteristics.

Physical characteristics of Site II monitoring locations may influence noise reduction attributed to ARFC overlay. These site characteristics include vertical or horizontal freeway alignment changes, the presence of noise barriers, the presence of existing buildings, the presence of heavy traffic on non-ARFC arterial roadways, ground surface composition, and topography. Monitoring locations were classified into categories using site characteristics. For example, Site II monitoring locations situated near a noise wall is a category **(Wall)**. Another category includes monitoring locations near freeway sections that increase in elevation to accommodate an overpass, topography, or a drainage feature **(Elevation Change)**. A third category involves a monitoring location adjacent to a freeway segment with a dense-graded AC frontage road or with a nearby AC arterial roadway **(Non-ARFC Road)**. Monitoring locations exhibiting noise reductions of less than 4 dBA are being analyzed using the site classifications.

V. Site III

Description

Research grade data was collected at the five Site III locations. The locations were selected to represent "Ideal Conditions" (no intervening barriers or future potential for barriers, topography varies by 2 feet or less, relatively flat topography with no slopes) and denote the highest quality field measurement sites. The purpose of the Site III study is to establish relationships between near-field and far-field measurements.

The Site III study includes wayside testing at 50 feet from the centerline of the adjacent freeway travel lane. Acoustical, meteorological, traffic, and pavement data were collected at Site III locations. Data will be used to evaluate general pavement acoustical properties and will be essential in confirming the application of a 4-decibel reduction to freeway noise analyses.

Field Activities

Site III data collection consisted of far field measurements obtained at five locations. At each location a test point was located 50 feet from the center of the travel lane, 5 feet above the pavement. This was considered the reference location. In addition to this point, a second 50-foot location measurement was obtained at a height of 12 feet. Additional test locations were also obtained at 100 feet and sometimes at a farther distance ranging between 175 feet to 250 feet. The acoustic measurement locations differ by site except for the 50-foot location.

In addition to the acoustic measurement locations, rigorous environmental monitoring occurred at Sites 3A and 3D. At these sites, three environmental towers were installed and windspeed and temperature obtained at 2 meters and 6 meters. Environmental data will be correlated to acoustic data and available before the end of the year.

Material samples from Site 3A and 3D have been obtained and are being analyzed. Test results should be available in January 2005.

Currently the site III data has not been completely analyzed. It is anticipated that this data will be available in early 2005.

Results
The Site 3 data is still being analyzed and is anticipated to be available in early 2005. Preliminary results indicate a 7 to 9 dBA reduction at the 50-foot locations.

VI. Recommendations

- Categorize each Site II and Site III monitoring location relative to site characteristics. For example, the monitoring location is near a noise barrier.

- Evaluate all Site II monitoring locations that did not exhibit a 4.0 dBA or greater noise reduction by assessing site characteristics and by comparing modeled noise values to measured noise levels.

APPENDIX 1

Approved ADOT Request Letter

Arizona Department of Transportation
Intermodal Transportation Division
206 South Seventeenth Avenue Phoenix, Arizona 85007-3213

ADOT

Janet Napolitano
Governor

Victor M. Mendez
Director

Bill Higgins
Acting State Engineer

April 16, 2003

Mr. Robert Hollis
Arizona Division Administrator
Federal Highway Administration
One Arizona Center, #410
400 East Van Buren
Phoenix, Arizona 85004

Dear Mr. Hollis:

BACKGROUND

Since 1976, the Arizona Department of Transportation (ADOT) has been using a rubberized asphaltic friction course as a roadway surface treatment to preserve existing asphalt and Portland Cement Concrete highways in Arizona.

Within the past three years, ADOT completed rehabilitation of two major highway projects in the Phoenix metropolitan area including adding general and high occupancy vehicle lanes to an eight-mile segment of Interstate 17 and a twelve-mile section of U.S. 60. Rubberized asphalt friction course was added to the existing PCC surface as a pavement preservation measure. Of particular importance to ADOT and adjacent neighborhoods was a significant reduction in vehicular noise using these highways. The resultant reduced noise impact was well received by both motorists and residents living near the freeways. Numerous media reports extolled the benefits of ADOT's "quiet pavement." Examples of recent newspaper articles are attached (refer to Attachment 1) citing the positive noise abatement qualities of rubberized asphalt. Additionally, editorials (refer to Attachment 2) followed, recommending that this new surface treatment be applied to all valley freeways.

Although ADOT has been using rubberized asphalt as a pavement preservation strategy for over twenty years, the Department formally initiated research on the noise reduction characteristics of asphalt rubber friction courses in 1995. These results were documented in the February 1996 Research Report, FHWA-AZ 96-433 (refer to Attachment #3). ADOT has continued this research effort jointly with CALTRANS in 2001/02 focusing on tire/pavements noise and how that factor relates to total noise at the receiver. ADOT has also programmed research funding in 2003/04 to further evaluate the impacts of atmospheric conditions upon noise propagation.

As a result, ADOT and the California Department of Transportation (CALTRANS) requested that a meeting be scheduled with FHWA administrative and technical staff to discuss the merits of quiet pavements and also to review regulation USC 23, C.F.R. 772. The resultant Quiet Pavement Symposium hosted by the FHWA on December 17-18, 2002 in Phoenix provided the impetus as a significant first step in recognizing the noise mitigation potential of pavement surfaces, particularly the use of a rubberized asphalt friction course to reduce pavement noise.

REQUEST FOR PILOT STUDY

Based upon the positive exchange of information and FHWA's proactive receptiveness to further research the benefits of "quiet pavement", **ADOT requests your approval to initiate a pilot study to evaluate the effectiveness of quiet pavement as a noise mitigation strategy.** In response to FHWA's approval of this study, ADOT has developed a comprehensive, work plan which will provide research level methodology to identify, evaluate and document the effectiveness of rubberized asphaltic friction course and possibly other pavements, as quiet pavement technology to reduce traffic noise on all sections of the Regional Freeway System and portions of Interstate 10 and 17 and US 60 in Maricopa County, Arizona.

Rubberized asphalt will be added to the remaining sections of Loop 202, (Red Mountain Freeway) from Higley Road to U.S. 60 and on Loop 202 (Santa Freeway) from Loop 101 (Price Freeway) to U.S. 60. ADOT will also address the following "hot spots" i.e. freeway locations where noise exceedances have been identified through current testing. These locations include the following freeway segments:

FREEWAY	SEGMENT	MILES	$M
Loop 101	U.S.60 – Chandler Blvd.	5.5	1.8
Loop 101	McDonald Dr. –McKellips Rd.	5	1.6
Loop 101	21 St Ave. – Tatum Blvd.	7	2.3
Loop 202	Alma School Rd– Val Vista Dr.	7	2.3
Loop 202	Gilbert Rd. – Val Vista Dr.	2.5	.8
Loop 202	Mesa Dr. – Gilbert Rd.	2	.7

All of the proposed freeways to receive rubberized asphalt surfacing are listed in the table on page 9 of the attached draft pilot study. A map of the Valley Freeway System illustrating the rubberized asphalt surfacing plan is attached to identify freeway segments and construction scheduling (Refer to attachment 4).

RESEARCH AND DOCUMENTED METHODOLOGY

Although the frictional characteristics of ARFC are well documented, ADOT commits to continue extensive documentation of frictional characteristics of ARFC overlays as a major component of its attached pilot plan (refer to Attachment 5).

In response to valley resident's complaints regarding traffic noise on Loops 101 and 202, ADOT initiated a comprehensive testing program to determine the validity and extent of their concerns. ADOT staff determined that meteorological factors including temperature, humidity, barometric pressure, wind speed and wind direction proved to have a significant impact upon noise propagation. Particularly, wind speed and temperature profiles can cause refraction of the propagating wave and have a significant effect on receptor noise levels. To ensure that ADOT will have the capacity to accurately measure these factors, the Department will purchase several Tactical Automated Meteorological Stations for field operations.

Other planned measurements techniques will include instrumentation, recording data analysis, weather considerations, and traffic parameters. All of the resultant data will be analyzed for accuracy and effectiveness. Annual summary reports will be provided to FHWA for validity, review and distribution.

ADOT will also continue collaborative research with CALTRANS to evaluate noise intensity measurements at the pavement/tire interface for collaboration using proximity and roadside noise measurements. This appears to be a promising technology, which would allow much more efficient and effective noise measurements if it can be correlated to roadside measurements.

In summary, ADOT's research and documentation will provide a basis to allow direct comparisons of different surface textures. New examinations of the physical data should address potential improvements in the noise environment without reducing overall safety or pavement durability. Additionally, the development of standardized testing methods to properly measure and characterize tire/pavement noise will permit direct comparison of data by various federal and independent research organizations and other states.

This research should help lead the FHWA in developing better design practices and provide uniformity and consistency in construction. This approach will provide data for national standards organizations and working groups as they develop policies and procedures for use by the American Association of State Highway and Transportation Officials.

Additionally, results of ADOT's study will provide a basis for additional guidance and direction for FHWA engineering and environmental staff to improve their decision-making process for pavement design and construction standards. Of particular importance will be relationships of safety, durability, reduced noise levels and cost effectiveness. Lastly, the study results provide potential for the possible use of pavement type and surface texture for highway noise abatement as a viable alternative to expensive noise barriers.

CLOSING

On behalf of the Arizona Department of Transportation, I wish to acknowledge the Federal Highway Administration's proactive role regarding the potential use of Quiet Pavement, specifically ARFC in ADOT's pilot study as a viable alternative noise mitigation strategy. You and your staff's involvement and support of this concept and willingness to initiate ADOT's pilot study are most appreciated.

Lastly, ADOT will continue its coordination, communication and cooperation with CALTRANS in this endeavor as both states initiate their respective studies. The attached work plan (refer to Attachment #5) will describe and document, in detail the testing process and methodology, and results. This data will be developed in concert with CALTRANS to ensure all testing supports the same objectives. Timely status updates and formal schedules will be developed as studies progress. It is anticipated that continuous involvement and communication among FHWA, ADOT and CALTRANS will be essential elements to the successful completion of this study.

In closing, ADOT wishes to express its collective appreciation for your and Ken Davis' administrative support and participation in hosting the December 17-18, 2002, Quiet Pavement Symposium in Phoenix and anticipate your continuing partnering throughout the pilot study.

Sincerely,

Bill Higgins

Bill Higgins
Acting State Engineer

Approved:

R E Hollis

Robert E. Hollis
Federal Highway Administration
Division Administrator
Arizona Division

Arizona Governor's Award for Quality
2001 Award Recipient

Attachments (5)

Cc: Robert Armstrong, FHWA
Ken Davis, FHWA
Bill Vachon, FHWA
Mark Swanlund, FHWA
Dr. Judy Rochat, US DOT Volpe Center
Dr. David Read, US DOT Volpe Center
Brent Felker, CALTRANS
Dr. Paul Donovan, CALTRANS
Keith Jones, CALTRANS
Bruce Rymer, CALTRANS
Dan Lance, ADOT
Larry Scofield, ADOT
Angie Newton, ADOT
Bill Hayden, ADOT

ATTACHMENT 1

NEWSPAPER ARTICLES

ATTACHMENT 2

MEDIA EDITORIALS

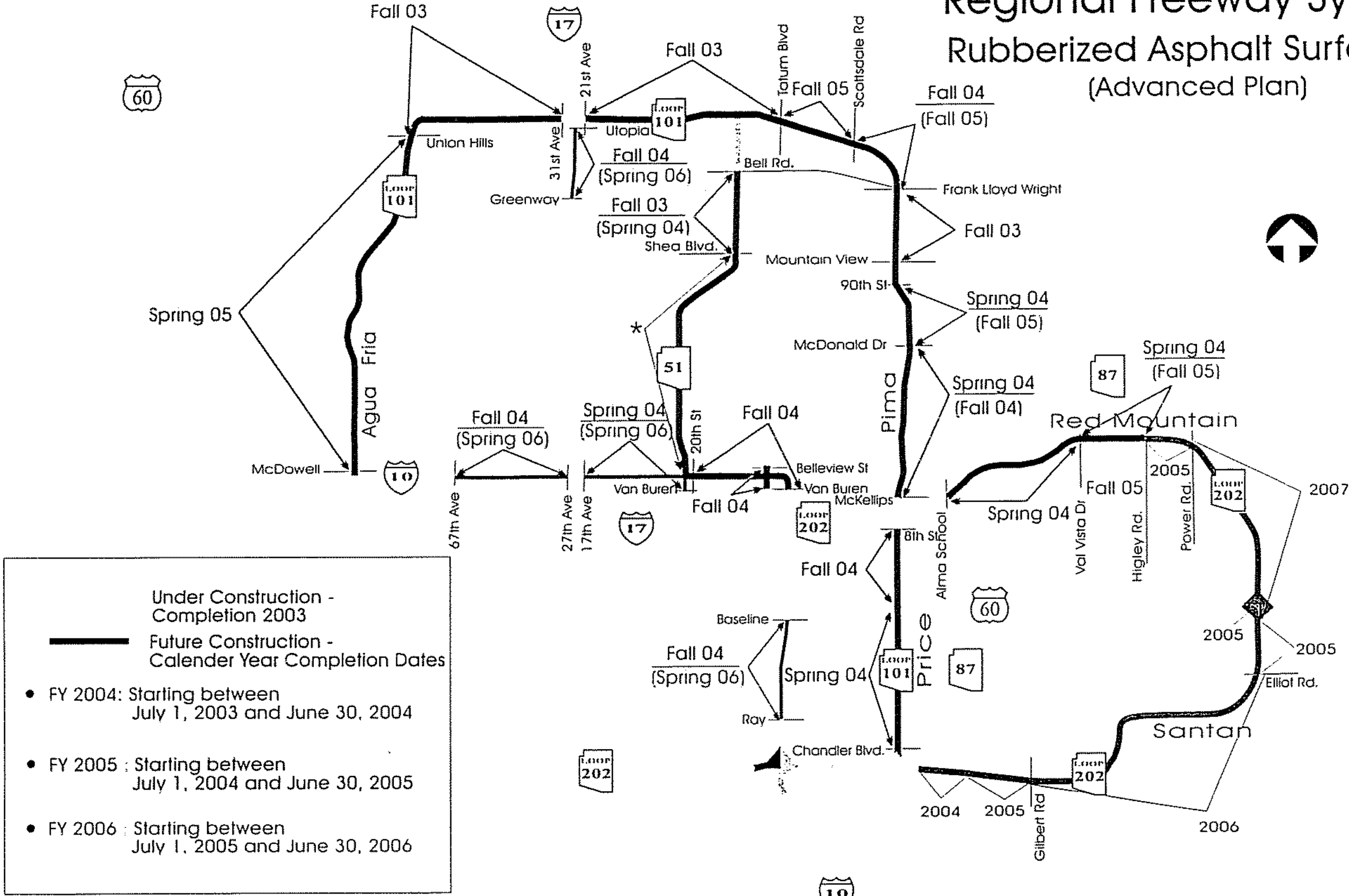
ATTACHMENT 3

ADOT - MAG

REGIONAL FREEWAY MAP

PROPOSED RUBBERIZED ASPHALT
SCHEDULE 2004-2006

Regional Freeway System
Rubberized Asphalt Surfacing
(Advanced Plan)



(Date) - Original Date

* SR 51 improvement project starting in 2003 between I-10 and Shea will include rubberized asphalt resurfacing.

May 19, 2003

MARICOPA ASSOCIATION of GOVERNMENTS

ADOT

ATTACHMENT 4

ADOT FINAL REPORT

A COMPARISON OF TRAFFIC NOISE FROM ASPHALT RUBBER ASPHALT CONCRETE FRICTION COURSES (ARACFC) AND PORTLAND CEMENT CONCRETE PAVEMENT (PCCP)

National Cooperative Highway Research Program

Synthesis of Highway Practice 268

Relationship Between Pavement Surface Texture and Highway Traffic Noise

ROGER L. WAYSON, Ph.D., P.E.
University of Central Florida

Topic Panel

ROBERT E. ARMSTRONG, *Federal Highway Administration*
JAMES D. CHALUPNIK, P.E., *University of Washington (retired)*
D.W. (Bill) DEARASAUGH, JR., *Transportation Research Board*
JAMES (Jim) GROVE, *Iowa Department of Transportation*
RUDOLF W. HENDRIKS, *California Department of Transportation*
HOWARD JONGEDYK, *Federal Highway Administration*
ROGER M. LARSON, *Federal Highway Administration*
REBECCA McDANIEL, *North Central Superpave Center*
KENNETH POLCAK, *Maryland State Highway Administration*

Transportation Research Board
National Research Council

Research Sponsored by the American Association of State Highway and Transportation Officials in Cooperation with the Federal Highway Administration

NATIONAL ACADEMY PRESS
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Subject Areas
Highway and Facility Design and
Pavement Design, Managment,
and Performance

RELATIONSHIP BETWEEN PAVEMENT SURFACE TEXTURE AND HIGHWAY TRAFFIC NOISE

SUMMARY

Pavement/tire noise has been studied for well over 30 years and several large databases have been compiled in the last decade. This synthesis is a summary of the research findings on this extensively studied topic. Summaries of selected sample sets are included to allow comparisons of the various results and reports. Because the reporting is extremely voluminous, care was taken to include up-to-date reports and those that summarize ideas from groups of individuals.

The synthesis first discusses basic acoustic fundamentals and then presents comprehensive details on pavement/tire noise generation and propagation. This permits individuals with various interests in the topic to better assimilate the information.

A survey was conducted to help guide the synthesis The important findings included:

- About half of the respondents had investigated noise effects from pavement surfaces.
- States specify standard pavement types by a factor of three to one
- Most states would consider changing pavement types for noise abatement.
- The majority of road surfaces are asphalt, PCC pavement is a distant second, followed by open-graded asphalt.
- The three areas that respondents considered most important for noise abatement are texture, speed, and tire tread design.

A summary of sound and pavement measuring techniques is also presented to help the reader better understand the reported results. Of note is that the two most used noise tests, the close proximity method and the passby method, do not seem to correlate. This is probably due to the fact that the close proximity or trailer method is a measure of noise generated at the tire while passby measurements include propagation effects of the pavement as well.

Measurement data, trends, and findings are discussed from many states, Europe, Africa, Japan, and Australia. Certain trends seem clear. In general, portland cement concrete (PCC) pavements have the advantage of durability and superior surface friction when compared to most dense-graded asphalt. However, data collected to date generally show PCC pavements to create more noise along the highway than asphaltic surfaces. Transverse tining is reported to cause the greatest sideline (roadside) noise levels and also may lead to irritating, pure tone noise. Randomized spacing and changing the tine width have been found to reduce the pure tone that is generated and reduce overall noise levels. Texture depth of the tining also seems to play an important role in sideline noise levels, although exact impact on noise generation has not been proven. Reports vary on the magnitude and impact of using various depths. Longitudinal tining was found to reduce the overall noise levels, but at a cost of reduced surface friction.

Recent research has shown some new concrete pavement textures to be worth further examination. Exposed aggregate (PCC) surfaces appear to provide better noise quality

characteristics as well as good frictional characteristics and durability. Porous PCC pavements also would seem to offer an alternative in the future to reduce sideline noise levels. However, new problems, such as appropriate maintenance and cleaning, must be solved for all porous pavement types.

In general, when dense-graded asphalt and PCC pavement were compared, the dense-graded asphalt was quieter by 2 to 3 dB(A). Even more benefit is shown for dense-graded asphalt when compared to transversely tined PCC pavements. Unfortunately, the dense-graded asphalt usually does not have the strong frictional characteristics of PCC pavements nor the durability.

Open-graded asphalt generally shows the greatest potential for noise reduction of sideline noise and reductions when compared to dense-graded asphalt. Reported reductions ranged from 1 to 9 dB(A). However, the noise reductions seem to decline with surface age and in approximately 5 to 7 years much of the noise benefit has diminished, although the surface is still usually quieter than PCC pavements. Also, porous asphalt suffers from problems such as plugging and deterioration due to freeze/thaw cycles. Other asphaltic surfaces, such as stone mastic and rubberized asphalt, also hold promise, but do not appear to give the noise reductions of open-graded asphalt although most are equal to or better than dense-graded asphalt.

Construction quality is an important consideration in the final overall noise generation no matter which pavement type or texture is selected. Also, safety must always be considered and, unfortunately, some surfaces that produce low sideline noise also have low friction numbers. It is the official policy of the Federal Highway Administration (FHWA), and the opinion of the American Association of State Highway and Transportation Officials (AASHTO) that a small amount of noise reduction is not worth sacrificing safety and durability. This means that the practicing highway design engineer must try to find a "happy medium" between noise control and maintaining a high level of safety.

The maintenance and safety considerations are also reviewed, as are interior noise levels. Of interest is that passby and interior noise levels do not seem to be correlated.

This report provides a comprehensive review, with extensive referencing, to help interested parties expand their explorations. The report provides a good starting point for the topic review, locating needed data, or continuing research.

CHAPTER NINE

CONCLUSIONS

Numerous measurements have been made of pavement/tire noise using both the trailer and the passby methods, although no significant correlation between the methods has been shown. Summaries of select sample sets are included in this report to allow comparisons by the reader. Combining these types of data would be suspect since so many variables differ in each data set. Although a large undertaking, development of an "average" data base for various pavement types, speeds, and vehicles (multiple tire types) would be of great benefit to the end users.

In the absence of combined data sets, certain trends still seem clear from the literature review. PCC pavements have the advantage of durability and superior surface friction when compared to dense-graded asphaltic pavements. However, PCC pavements generally create more noise along the highway. Transverse tining seems to cause the greatest sideline (passby) noise levels. It also appears that the surface texture of uniform transverse tining, especially if spaced over 26 mm (1 in.), generates the most tire/pavement noise and the most annoying tones. However, researchers have reported that random spacing may reduce and even eliminate the annoying pure tone generated by transverse tining.

Longitudinal tining was found to reduce the overall noise levels, but at a cost of reduced surface friction when compared to transverse tining. Also, surface friction decreases more rapidly over time for longitudinal tining than transverse tining.

Texture depth of the transverse tining also seems important to sideline noise levels from PCC pavements. Australian test results showed that an increased depth led to a slight noise benefit, while trends for U.S. data showed even more benefit from increased depth. Some conflicting data in the United States suggest that other surface characteristics, such as tine spacing, construction techniques, and aggregate size, must also be considered concurrently.

Results show that the ". . . exposed aggregate surface appears to provide better noise quality characteristics. . ." This surface also has good frictional characteristics and could provide durability as well as noise reductions. This conclusion was echoed by several European studies. For example, an exposed aggregate surface with a top layer containing a maximum 8 mm (0.31 in.) aggregate size, showed a 5 dB(A) reduction when measured by the trailer method. A frequency analysis showed important reductions in the 500 to 2,000 Hz range that can cause annoyance as well. A significant noise reduction or frequency shift was not shown when U.S. researchers compared a transverse tined surface (26 mm (1 in.) uniform spacing)) with a European exposed aggregate texture design. Two states showed only a 1 dB(A) reduction. Construction techniques were thought to be the problem, especially aggregate size used in the final course. Similar construction problems in Australia reinforce this idea.

Porous PCC pavements may offer a variable noise abatement option. However, these pavements suffer from plugging, deterioration with freeze/thaw cycles, and reduced effectiveness when using deicing agents.

In general, when dense-graded asphalt and PCC pavement are compared, the dense-graded asphalt is quieter by 2 to 3 dB(A) and even more benefit is shown if the dense-graded asphalt is compared to transversely tined PCC pavements. The noise benefits of the asphaltic pavement are reduced with surface wear. Also, the dense-graded asphalt does not have the strong frictional characteristics of PCC pavements nor the durability.

Open-graded asphalt shows the greatest potential for noise reduction for passby noise. Reductions when compared to dense-graded asphalt ranged from 1 to 9 dB(A). However, the noise reductions seem to decline with surface age and in approximately 5 to 7 years, the noise benefit diminishes, although the surface is still quieter than most PCC pavements. Porous asphalt suffers in a fashion similar to porous PCC pavements from plugging, freeze/thaw impacts, and reduced effectiveness of deicing agents. Fortunately, frictional characteristics seem to be good for porous asphalt.

Other asphaltic surfaces, such as stone mastic and rubberized asphalt, also were thought to hold promise, but do not appear to give the noise reductions of open-graded asphalt or they have implementation problems.

Construction quality is an important consideration in the final overall noise generation, no matter which pavement type or texture is selected. It was shown that large variations in noise levels and frictional characteristics can occur from the same type of pavements if construction techniques or materials are varied.

Safety must always be considered. Some surfaces that may lead to noise reduction also have low friction numbers. It is the official FHWA policy that a small amount of noise reduction is not worth sacrificing safety or durability. This means that the practicing highway design engineer must try to find a "happy medium" between noise control and safety. This may result in decisions unpopular with highway neighbors.

A survey was also conducted to help guide this synthesis. The important findings included:

- About half of the 55 respondents had investigated noise effects from pavement surfaces.
- Standard pavement types are specified by a factor of 3 to 1 by states, territories, countries, and agencies.
- Most respondents would consider changing pavement types for noise abatement.
- The majority of road surfaces are asphaltic, PCC pavements rank second by a wide margin, and open-graded asphalt makes up the remaining fraction.
- The three areas considered most important for noise abatement are texture, speed, and tire tread.

More data is needed on safety considerations, such as wet weather accident rates for various textures. The pavement microtexture is extremely important in reducing wet weather accidents but not important for noise generation/propagation. However, macrotexture is needed for surface friction and is directly related to noise generation and propagation. The two must be considered together to reduce noise, but without sacrificing safety. Smaller aggregate sizes, less than 10 mm (0.39 in.), are needed for asphaltic surfaces to provide adequate frictional effects and result in reduced noise levels.

Differences in sound transmission mechanisms result in different trends for interior noise and exterior, sideline noise. The quietest pavement for interior noise may not be the same for noise at the side of the roadway.

In sum, more research is needed to address the issues of noise created by the tire/pavement interactions. Further analysis of the varying test results and findings is necessary to allow direct comparisons of different surface textures. New examinations should address potential improvements in the noise environment, without reducing overall safety or pavement durability. Work is also needed on standardizing test methods to properly measure and characterize tire/pavement noise and permit direct comparison of data by various researchers and regions. This would help lead to better design practices and construction. International Standards Organizations working groups are in search of such methods. Finally, additional guidance and direction should be developed to improve the decisionmaking process for pavement design and construction. This process must appropriately consider the relationships of safety, durability, noise, and economic cost. At present it is FHWA's official policy that a small noise decrease must not come at the expense of safety. However, the possible use of pavement type and surface texture for highway noise abatement seems a viable alternative.

Excerpts From

A Spray Based Crumb Rubb Technology In Highway Noi Reduction Application

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Director of Government Relations
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October, 1999

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RPA Reports

HIGHWAY NOISE BARRIERS

When vehicles are in motion, friction between the vehicle's body and the air touching the vehicle will take place. Such friction renders an aerodynamics effect that noise will be generated because of the gradient in the air pressure field induced by the friction. This pressure field will propagate to generate noise that can be heard at significant distances. Additionally, the contact of grooved tires on pavement surfaces occurring at high speeds creates a substantial sound pressure field as well as engine operations and exhaust systems. This type of noise is called traffic noise since it is originated by moving vehicles. Its acoustic spectrum is of multiple frequencies. The majority of the spectrum falls within the frequency range of 250 Hertz and 4000 Hertz[4]. The noise within this frequency range can be easily heard by the human ear, and can cause great discomfort. To control the propagation of this traffic noise, common practice is to build noise barriers along highways so that noise will be contained and absorbed within barriers, and will not propagate to any significant distance.

However, most highway noise barriers are built with pre-cast concrete or concrete blocks/slabs. The study shows that these barriers are of very high acoustic reflectivity (95% and above[5]) and of low sound absorption for the frequency band of highway noise between 250 Hertz and 4000 Hertz. So the effectiveness of concrete noise barriers in controlling vehicle noise is far from being satisfactory.

With the drastic increase in highway traffic in the last two decades, the effort to develop new and better noise-reduction barriers for highways as well as airport and other applications has been intensified. It is predictable that such an intensification will continue because noise poses an increasingly environmental threat. In recent years, some notable progress has been made in this respect. It has been reported a section of polycarbonate noise wall was built in 1996 near Culver City park in Los Angeles, California. The polycarbonate noise reduction panels are developed by Quitite International, a company based in Los Angeles, California, and the panels are made by Lexan® polycarbonate plastic produced by General Electric. In addition, a jet engine testing shelter was installed also by using Lexan® polycarbonate plastic at Albany airport, Albany, New York in 1997 [6]. Another development is the noise barrier system developed by Carsonite International in Early Branch, South Carolina, and the noise barriers are lightweight hollow panels made of tongue-and-groove planks of reinforced composite material filled with crumbed tire rubber. A few sections of Carsonite noise barriers have been built in Long Beach, California. Traditional noise barrier walls have a flat surface. Now new designs are experimented with non-flat surface textures (Figure-1).

Figure-1 Grooved noise barrier walls near Highway 101 in Tempe, Arizona

These newly developed noise barriers exhibit a much better performance than concrete with respect to the capability of sound absorption and transmission loss, but the noise reduction is not the only criterion. In fact, there are other crucial criteria in constructing noise barriers. These criteria include: (1) cost effectiveness, (2) technology maturity, (3) durability, (4) low cost and convenience in installation, (5) low cost and convenience in maintenance and repair, and (6) aesthetics. The conventional concrete noise barriers meet those criteria very favorably. For example, the average cost to build one foot of concrete noise barrier (typical 6 to 8 feet tall) is about $20 ($20/ft). Polycarbonate plastic or composite noise barriers are very costly, and much less competitive in those criteria in comparison to concrete ones. This is why so far the progress made in replacing concrete noise barriers with aforementioned new noise reduction materials is very limited.

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CRUMB RUBBER

From an engineering point of view, crumb rubber has a number of special thermo-mechanical and chemico-physical properties. Crumb rubber is made by shredding scrap tires and as such, it is a particulate material free of fiber and steel. It is made commercially available in 50-pound bags or 2000-pounds bulk bags. The size of the rubber particles is graded. The finest one can be as small as about 0.2mm (Mesh #80) and below, The gradation commonly used in rubberized asphalt pavement is between about 2.0 mm to 0.5 mm (Mesh #10 to Mesh #40). Crumb rubber is light in weight and is durable. It can last for a long period of time in a natural environment. From the safety consideration, crumb rubber is a non-toxic and inert material.

The idea to explore the possible application of crumb rubber in the noise reduction application merges from the fact that [7] bulk rubber panels have a much better sound absorption capability than concrete blocks/slabs do. Now, since crumb rubber is made in a state of loose granules, using crumb rubber to make panels provides the opportunity that the panels now may be fabricated in the way that they can contain a large percentage of air voids. Rubber panels containing high air porosity will certainly increase the sound absorption capability in comparison with bulk (zero porosity) rubber panels.

More importantly, crumb rubber is a recycled material, as more is consumed, the better it will be to help reduce so-called the scrap tire pollution. Also, considering that most new noise barriers recently developed or under development are made from plastic that is a high-energy-consumption product made by chemically processing fossil oils, and the resource for fossil oils on earth is limited. Therefore, the choice is obvious that developing crumb rubber for its application in noise-reduction can lead to a win-win situation if successful.

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ACOUSTIC ABSORPTION TEST (ASTM C423-90a)

The most critical parameter in characterizing the capability of a material of how well it can absorb sound or noise is called the acoustical absorption coefficient (AAC). A sound wave carries certain amount of the energy called sound energy. When a sound wave hit a material, portion of the sound energy will be reflected or "bounced" back. Simplistically speaking, from the noise reduction point of view, the lesser sound energy being bounced back, the better the effect of noise reduction. A value AAC=0 means sound energy being reflected completely, and a value AAC=1 means that all the sound energy is absorbed by the material, which is the best in noise reduction. American Society of Testing and Materials (ASTM) issued a standard in how to conduct the test of acoustical absorption coefficient on a specimen made by a specified material and how to determine the value of AAC based on the test result. The standard is ASTM C423-90a.

As part of this study, a testing specimen for ASTM C423-90a is fabricated (Figure-2). The mix design is 0.8 (crumb rubber) to 1 (bonding agent) with a mixed size of rubber particles using the second and third spray devices referred in above. The dimension of the specimen is quite large. It consists of four panels and each panel is 48 inches by 48 inches by 1 inch. Then, the specimen is shipped to Riverbank Acoustical Laboratories (RAL) at Geneva, Illinois, and the test is performed there in September, 1999. RAL is a highly reputable laboratory in conducting acoustic related tests. The testing result of the acoustical absorption coefficient versus frequency is obtained and is plotted in Figure-3. For the comparison purpose, also displayed in Figure-3 are the same coefficient for concrete and the aforementioned Carsonite noise barriers. It can be seen that the crumb rubber based specimen shows superiority in acoustical absorption.

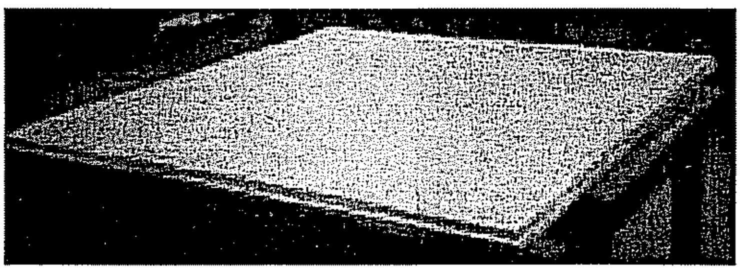

Figure-2 Crumb rubber based test specimen for ASTM C423-90a

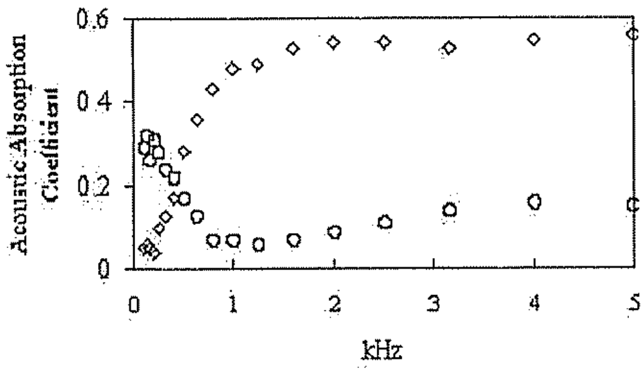

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Figure-3 Acoustic absorption coefficient versus frequency. Square symbols represent for concrete noise barriers, circular symbols for Carsonite noise barriers, and diamond symbols for the crumb rubber mix.

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ATTACHMENT 5

ADOT'S QUIET PAVEMENT
TECHNICAL PILOT STUDY

Attachment 5
Arizona Department of Transportation (ADOT)
Quiet Pavement Pilot Program
4/16/03

1. Introduction

This program will evaluate highway traffic noise reduction benefits gained from the use of asphalt-rubber asphalt concrete friction courses (ARFCs) in Arizona. While highway pavement selection has historically been based upon safety and durability, recent interest in quiet pavements requires that noise characteristics also be considered. This study is intended to demonstrate the effectiveness of quiet pavement strategies and to evaluate any changes in their noise mitigation properties with time.

2. Background

During the early and mid 1990s ADOT received input from the public regarding noise generated by the current PCCP textures employed in the Phoenix Metropolitan area. This input often included a comparison to the ARFC sections that had been placed as experimental features. ADOT's own internal observations also supported the reduced noise characteristics of ARFCs.

To address this issue, ADOT initiated a research project in 1995 to compare traffic noise levels generated by ARFCs and PCCP surfaces. The study, conducted by JHK and Associates, was originally developed to provide baseline measurements to enable observation of selected pavement noise characteristics over time. To accomplish this, both roadside measurements and vehicle-based measurements were obtained. The vehicle-based approach was a low budget attempt to provide network level capability for measuring the change in noise generation characteristics.

The results of the 1995 testing indicated that: "Roadside noise levels near a tined PCCP surface were 3.3-5.7 dBA greater than the levels measured near an adjoining ARFC surface. Based on four separate hourly measurements, the average difference between the two surfaces was 4.7 dBA.

The study also reported differences in properties between ARFC of different ages and dramatic differences between PCCP surfaces with different texture properties (i.e. grinding, grooving, and tining). Unfortunately, the study was quite limited and most of the issues were not addressed in a comprehensive manner.

In 1998 an attempt was made to resurvey the sections evaluated in the 1995 study using the vehicle-based system. As was originally feared, the very modest approach to a vehicle-based measurement system proved inadequate to re-survey the sections and was subsequently abandoned.

ADOT continued to pursue the development of a near field measurement system. Finally, in 2002 ADOT had an ISO standard Close Proximity (i.e. CPX) trailer constructed. This trailer complied with the ISO standard in every way except tire types used for testing. The European community uses smaller diameter and narrower tires than used on US highways. So more representative tires were selected for the near field testing.

During the summer of 2002 ADOT conducted a network level survey (i.e. CPX testing) of ARFCs ranging in age between 3 years and 12 years. Several projects were sampled for each age category. The results of this testing are shown in Figure 1. The results indicated that

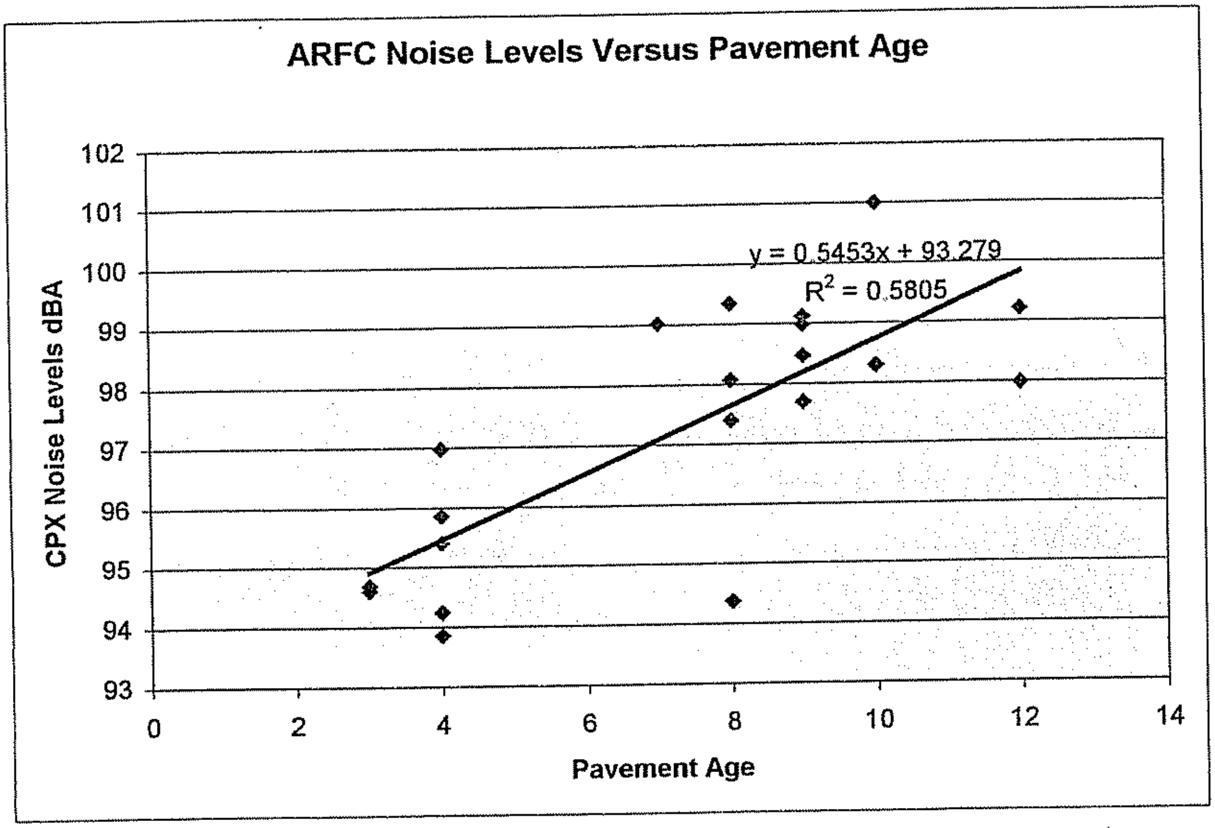


Figure 1: Graph of CPX Noise Levels for ARFC as a Function of Pavement Age

ARFC surfaces typically produced CPX noise levels between 94 and 99 dBA throughout their ten-year design period. The data further suggested that there was approximately a 5-dBA reduction in noise attenuation characteristics with time.

In the summer of 2002, additional testing was conducted on selected PCCP tining textures to evaluate whether additional noise reduction could be achieved by modifying the current PCCP tining procedures. Three tining textures were evaluated on a newly constructed PCCP and existing PCCP section on SR 202 between Gilbert and Higley road. The textures included ADOT's current uniform transverse tining, a one-inch uniformly spaced longitudinal tining, and the Wisconsin DOT random transverse tining. The results of this

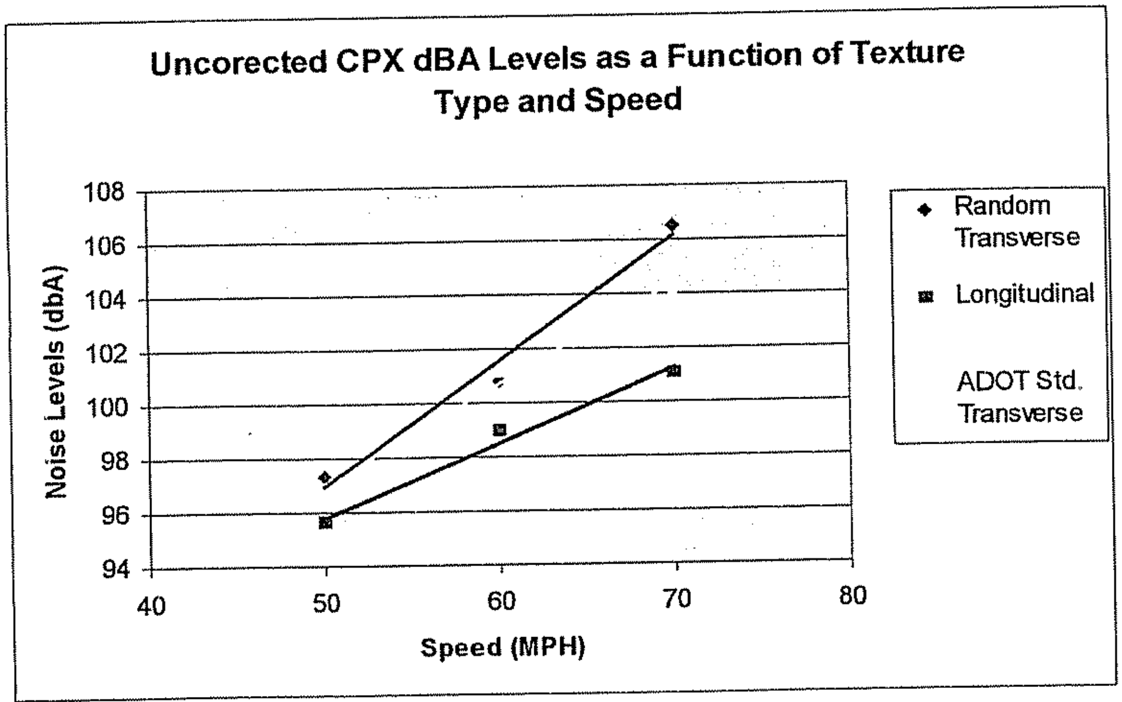


Figure 2: Graph of CPX Noise Level as a Function of Pavement Speed and Texture Type

effort are shown in Figure 2. As evident in Figure 2, the FHWA promoted Wisconsin random texture did not produce a quieter pavement texture. It was actually the noisiest surface. Subsequent narrow band analysis indicated that the tonal spikes were removed by the random texture as purported, but the resulting total noise levels were still higher. This is presumably due to the wider effective spacing of the Wisconsin specification. At that time ADOT began change ordering longitudinal tining as a replacement for the uniform random tining on active construction projects.

An additional observation at that time was that the standard ADOT uniform transverse texture produced a CPX noise level of approximately 101 dBA at 60 MPH. This is 2-3 dBA higher than attained by ARFCs at the end of their design life. This indicated that current PCCP construction technology could not achieve the noise reduction benefits of ARFCs.

Due to the surprising findings regarding PCCP texture types, additional testing was pursued. This involved conducting pass-by testing alongside each of the tining types. The results of that testing are shown in Figure 3. As evident in Figure 3, the random tining was the noisiest, followed by the ADOT uniform transverse followed by the uniform longitudinal tining. The relationship between the texture types was similar to what was found with CPX measurements.

During this same time period, citizen complaints were on the rise regarding the noise generation characteristics of PCCP in the Phoenix area. The recent overlay of the US 60 design build project with ARFC further fueled complaints as the ARFC surfacing

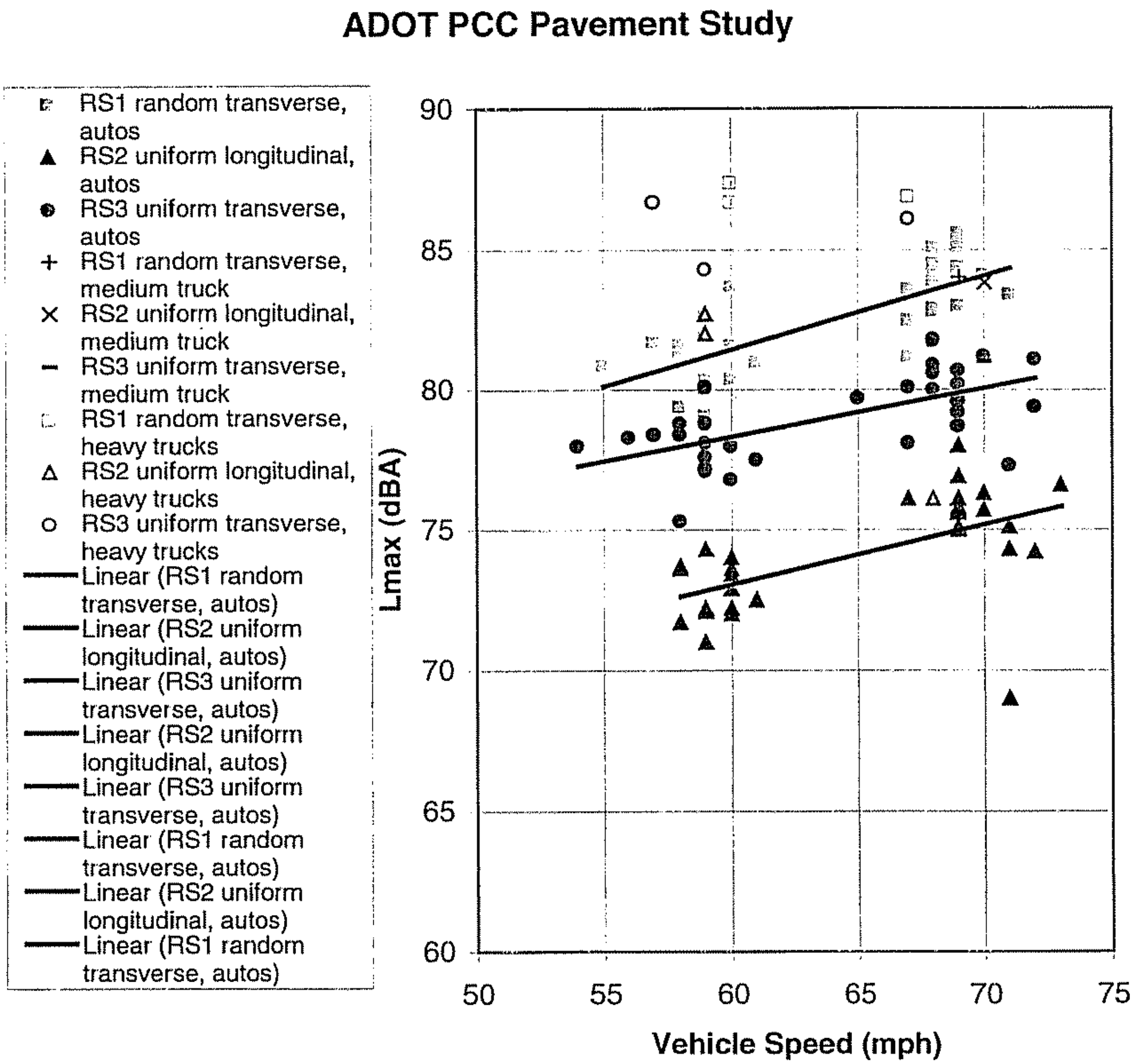


Figure 3: Graph of Pass-by Noise Levels Versus Vehicle Speed and Pavement Tining Type

dramatically reduced in-vehicle noise levels making motorists more aware of the differences between pavement types and the effectiveness of quiet pavements.

Based on citizen input in the Scottsdale area regarding a section of SR 101, a one-mile long section of PCCP was overlaid with ARFC to demonstrate the effectiveness of the quiet pavement strategy. Before and after close proximity testing indicated that there was approximately an 11-dBA difference in noise levels.

Far field test results taken at the residence locations are shown in Figure 4. The pre and post overlay noise levels are indicated at each monitored location.

As a result of the previous studies discussed above, ADOT will utilize a noise reduction adjustment factor of – 4 dBA for ARFC in the Quiet Pavement Pilot Program.

3. Areas of Application

ADOT requests the application of this pilot program to all of the projects listed in Table 1. The projects represent 27 segments, which will be completed through six separate construction projects over the next three years. All pilot program projects will be Type I projects, as defined in ***23 CFR Part 772 - Procedures for Abatement of Highway Traffic Noise and Construction Noise.***

4. Project Analysis

When conducting traffic noise analyses for projects in the above locations (where ARFCs will be utilized), ADOT will apply a pavement adjustment factor to reduce the overall A-weighted predicted noise levels by 4 dBA. ADOT will apply the adjustment to predicted traffic noise levels, both to identify highway traffic noise impacts and to design highway noise barriers. When walls are to be constructed, the combination of the noise reduction due to pavement and the noise reduction resulting from the barrier's insertion loss must result in a substantial noise reduction, i.e. at least a 5-dBA noise reduction.

NOTE: When using ***STAMINA 2.0/OPTIMA***, a "shielding factor" of 4 will be applied in the calculations. When using ***FHWA TNM***, "average pavement" and an "adjustment factor" of – 4 will be applied in the calculations. Prior to applying the 4-dBA reduction, either model must be calibrated to the existing condition by comparisons of the modeled noise level results to high quality noise level measurements obtained at existing pavement sites using video recorded traffic counts and classifications as input. Noise barriers should also be designed to allow for additional height to be added to the barriers, if necessary.

5. Program Commitments

If measurements after ARFC construction determine that a reduction of at least 4 dBA is not being achieved, ADOT agrees to the following to provide necessary measures to abate highway traffic noise levels in perpetuity:
If quiet pavements are used as a noise mitigation strategy in the noise modeling, and it is determined the pavement has not achieved the assumed level of mitigation, ADOT will resurface the roadway to achieve the assumed level of noise reduction or provide a similar level of noise mitigation through more conventional techniques, like barrier walls or berms.

6. Data Acquisition

ADOT will collect data through actual field measurements for each pilot project with an intention to collect data necessary to accomplish the following:

- Quantify the acoustical properties of new pavement as compared to existing pavement;

- Quantify the variation of pavement acoustical properties with age;
- Quantify variation of pavement acoustical properties with season;
- Determine the correlation (if any) between physical pavement characteristics (such as macro texture, void content, impedance) and the pavement's acoustical properties, so that acoustical performance can be determined by material testing.
- Determine the correlation (if any) between wayside and near-field acoustical measurements, so that near-field measurements alone may be used for future pavement noise evaluations.

For the purposes of this workplan, each construction project will be evaluated as a pilot project. For each pilot project (i.e. construction project), ADOT will develop an evaluation plan for submission to the FHWA for approval. This plan will identify the location and description of all Site 2 measurement sites; the measurement methodology, including specific instrumentation type and test procedures. The Site 1 test locations will be as described in Table 2. The Site 3 locations will be submitted to the FHWA for approval along with the test plan for these locations.

The proposed plan is shown in Table 2. The definition of each of the site types (i.e. 1,2 & 3) are described below:

The test plan begins with a column designated as category to distinguish the categories of testing. Test type provides additional clarity. Test method is the referenced standard for the testing. Test duration indicates the period of time that the respective test would occur over. The test frequency indicates how many times a year the test will be conducted. The before and after columns refer to pre-overlay and post-overlay testing. The site type column will be explained in greater detail below. The evaluation period indicates how many years each of the specific tests will be conducted.

This plan is based upon three different site conditions, referred to as site type in Table 2.

- **Site 1** designates ADOT's typical pavement management system data collection activity. That is, at each milepost, the specified pavement attribute is measured in the travel lane. This testing would occur for all milepost locations included within the construction of the quiet pavement overlays. Minimal environmental data would be collected at these sites. Simply, air and pavement temperatures.

  In addition to the Site 1 locations, the near-field testing will be conducted at both the Site 2 and 3 locations.

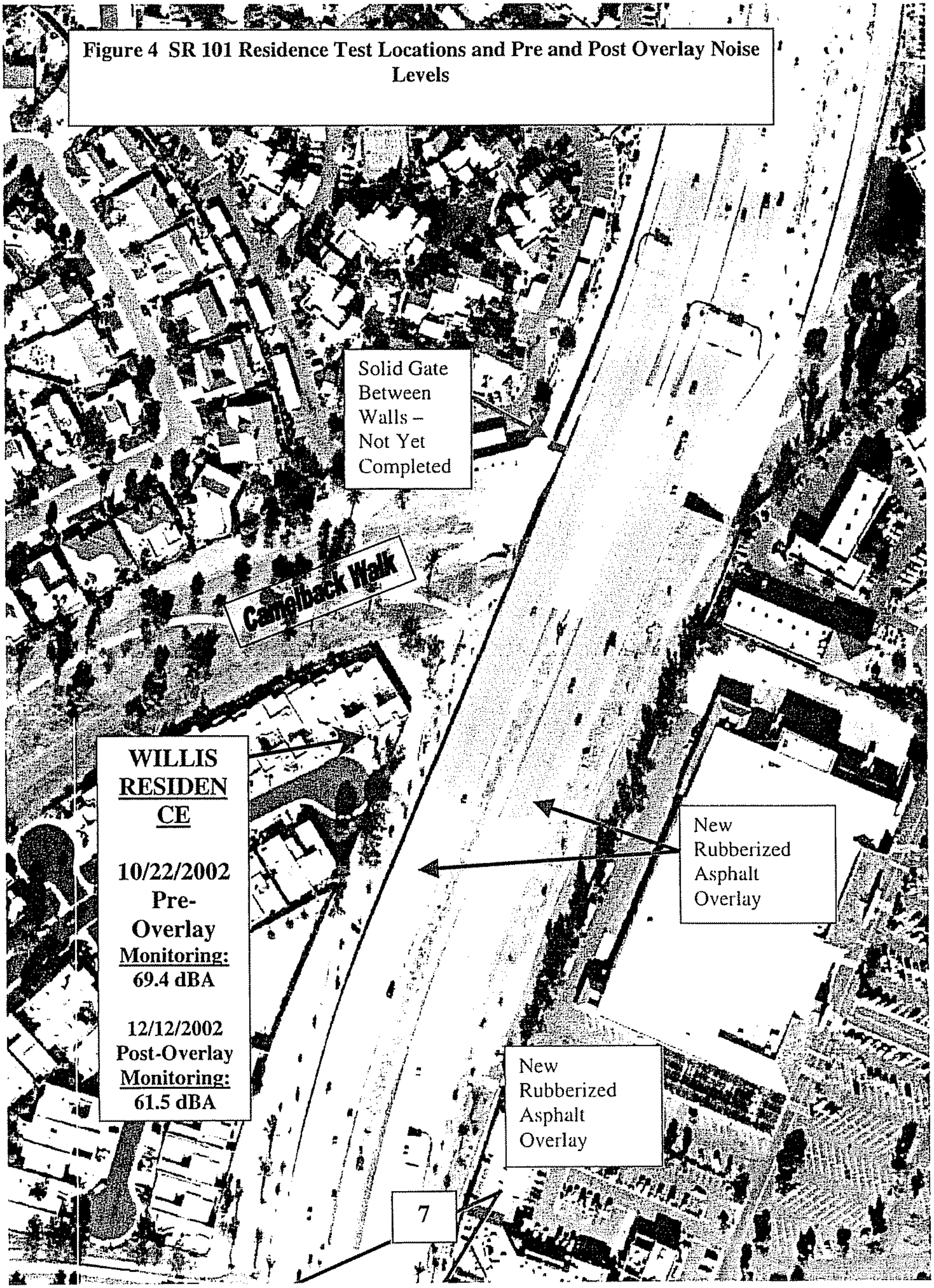


Figure 4 SR 101 Residence Test Locations and Pre and Post Overlay Noise Levels

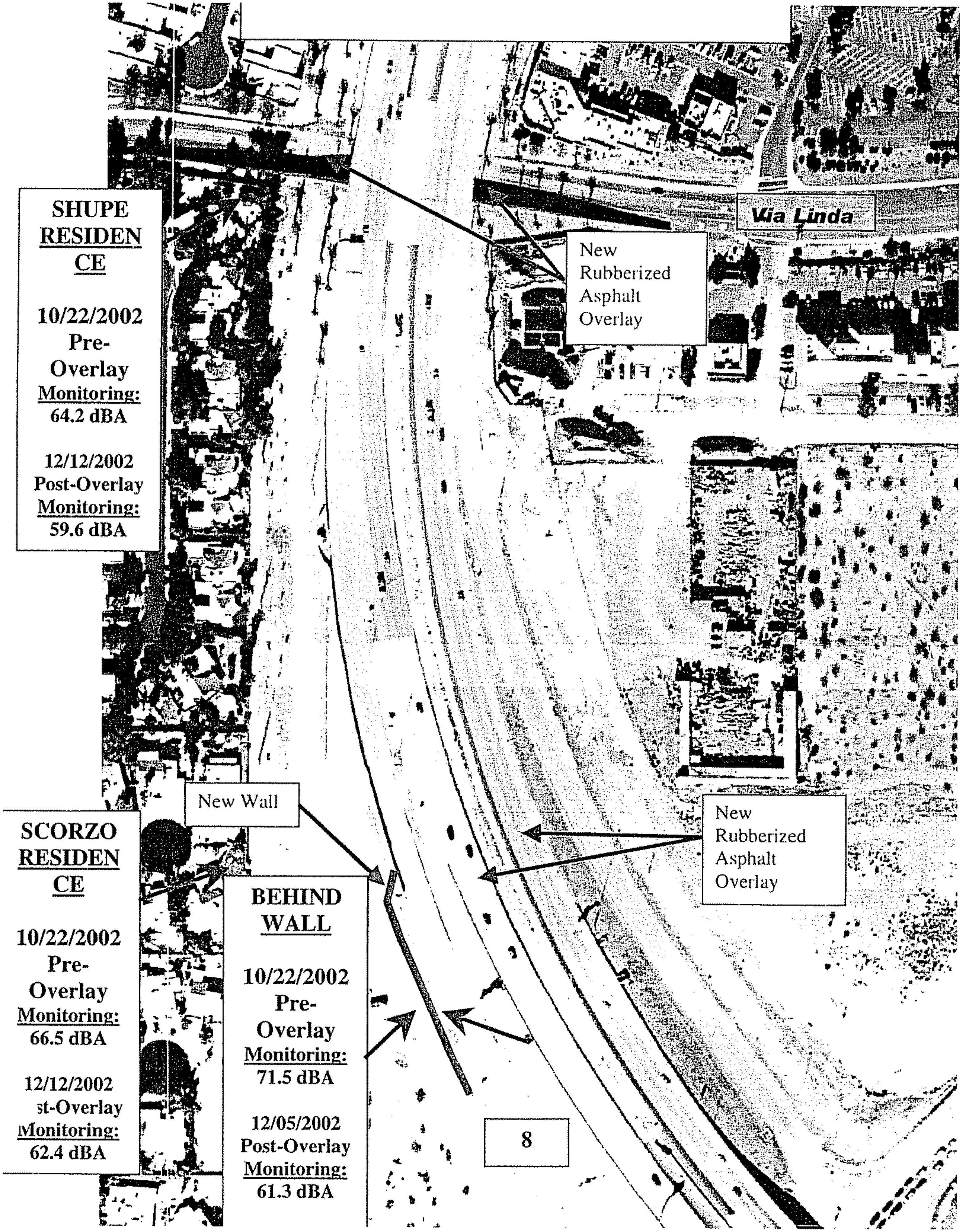

Via Linda
New Rubberized Asphalt Overlay
SHUPE RESIDENCE
10/22/2002 Pre-Overlay Monitoring: 64.2 dBA
12/12/2002 Post-Overlay Monitoring: 59.6 dBA
New Wall
New Rubberized Asphalt Overlay
SCORZO RESIDENCE
10/22/2002 Pre-Overlay Monitoring: 66.5 dBA
12/12/2002 st-Overlay Monitoring: 62.4 dBA
BEHIND WALL
10/22/2002 Pre-Overlay Monitoring: 71.5 dBA
12/05/2002 Post-Overlay Monitoring: 61.3 dBA
8

Table 1 - List of Roadway Segments Where ARFC Overlays Will Occur

Route	Section	Miles	Residential * Density	Existing Noise Walls]	Hot ** Spots
101 PM	Raintree - Mt. View	3	H	Y	N
101AF	Union Hills - 31st Ave	6.5	H	Y	N
101PM	21st Ave - Tatum	7	H	Y	Y
143	Bellview - Van Buren	1	M	N	N
101 PM	McDonald - McKellips	5	L	N	Y
101 PR	8th St. - US60	3	H	Y	N
202 RM	20th St. - VanBuren	4	M	Y	N
51	Shea - Bell	4	H	Y	N
101 PR	US60 - Chandler Blvd	5.5	M	Y	Y
202 RM	Alma School - Mesa	2.5	M	Y	Y
202 RM	Gilbert - Val Vista	2.5	M	Y	Y
202 RM	Mesa Dr. - Gilbert	2	L	Y	Y
101 PM	Tatum - Raintree	8	N	N	N
101 PM	90th St. - McDonald	3	N	N	N
202 RM	Val Vista - Higley	2	N	N	N
101 AF	McDowell - Thomas	1	M	N	N
101 AF	Thomas - Campbell	1.5	N	N	N
101 AF	Campbell - Northern	3.5	N	N	N
101 AF	Northern - Olive	1	L	N	N
101 AF	Olive - Grand	2	H	N	N
101 AF	Grand - Thunderbird	1.5	L	N	N
101 AF	Thunderbird - Union Hills	3	M	Y	N
I-10	67th - 51st	2	M	Y	N
I-10	51st - 27th Ave	3	M	Y	N
I-10	15th Ave - Van Buren	4	H	Y	N
I-10	Baseline - Ray	4	M	Y	N
I-17	Greenway - Utopia	2.5	M	N	N
101	31st Ave - 21st Ave	1	N	N	N
101	McKellips - 8th St	1.5	N	N	N
101 PM	Mt. View - 90th St	0.7	NA	NA	N
202 RM	Van Buren - Alma School	7.5	N	N	N

*** H=High Density, M= Medium Density, L=Low Density, N= No Residential, N.A.= No Action**
**** Hot Spots – Areas where ADOT has measured noise levels that exceeded 64 dBA and qualify for additional mitigation under the ADOT Noise Abatement Policy.**

- **Site 2** designates the sites that would typically be called conformance or compliance testing in ADOT's current program. These sites are where ADOT would conduct before and after studies to evaluate how the residences are impacted. As previously mentioned it is anticipated at this time that approximately 6 construction projects will be used to construct all the overlays.

This test plan assumes a minimum of three Site 2 locations per construction project for an approximate total of 18 locations. It should be emphasized however; that the Site 2 locations are extremely specific to the particular project and, in deed, have to be established project by project due to complexity and impacts. A minimum of three per project has been established to provide a minimal guaranteed representation. As mentioned in the Volpe document, a 50 ft measurement would be attempted at each of these locations whenever possible. However, it is not likely that this can be done at all locations due to obstructions or reflecting surfaces interfering. Environmental data would be collected at the same time as the acoustic data at these locations. The Site 2 locations would be approved for each project in a project specific workplan. It should be noted that at a location where the 50 ft measurement can be obtained, that location would consist of both Site 2 and Site 3 locations.

- **Site 3** designates the research grade sites. These are the locations that most closely resemble the "Ideal Conditions". These are also the sites where relationships between near field and far field correlations will be attempted and are the highest quality field measurement sites. At Site 3 locations, acoustical, meteorological, traffic, and pavement data will be collected.

  Site 3 will include all way-side testing within 50 feet of the roadway. Data collected at Site 3 locations will be used to evaluate the general performance of the pavement acoustical properties, including the evaluation of the applied 4-dBA reduction.

The monitoring period will continue for the service life of the first overlay, whether that be 10 or 15 years. No additional monitoring is proposed for subsequent overlays. However, if the first overlay functionally fails, within six years or less, the department would monitor the replacement overlay for the period necessary to have provided a minimum of ten years of evaluation for that segment of roadway. That is, if the first overlay lasted six years, four additional years of monitoring would occur for the replacement overlay.

7. Report

ADOT will submit an annual report that summarizes the data from all pilot projects to the FHWA Arizona Division Office.

8. Public Reaction

ADOT will document public reactions on the noise benefits of ARFCs throughout the life of each pilot project. Comments will be collected by various methods, such as letters, e-mails, telephone calls (possibly a hotline), newspaper articles, surveys, or public meetings. ADOT will include the public comments in the annual report for each pilot project.

9. Changes to the Pilot Program

As additional knowledge and experience is gained regarding the use of ARFCs in Arizona, ADOT or FHWA may request changes to the Quiet Pavement Pilot Program. This may include changes in the areas of application or changes to the data acquisition plan or the termination of data acquisition or portions of the data acquisition for specific projects. Both ADOT and the FHWA Arizona Division Office must mutually agree upon requests for changes.

Test Type	Test Method	Test Duration	Test Frequency	Test Location	Before Test	After Test	Site ** Type	Evaluat Period
ar Field								
Close Proximity	ISO 11819-2*	7 second	Twice/Yr	MP	X	X	1,2,3	5+L Yrs
Noise Intensity	Caltrans Meth	7 second	Same as CPX	Same as CPX	X	X	1,2,3	"
Far Field (FF)	--See Note	2 Five Hr	Twice/Yr	Selected Residences	X***	X	2	3+L
	--See Note	2 Five Hr	Twice/Yr	50, 200, Distant	X***	X	3	5+L
Volume	--See Note -	SA FF	Twice/Yr	Rep. FF Testing		X	2, 3	SA FF
Speed	--See Note	SA FF	Twice/Yr	Rep. FF Testing		X	2, 3	SA FF
Surface Characteristics								
Outflow Meter		NA	Annually	Selected Location		X	3	5+L Yrs
CT Meter	ASTM E 2157	NA	Annually	Selected Location		X	3	5+L Yrs
Dynamic Fric Test	ASTM E 1911	NA	Annually	Selected Location		X	3	5+L Yrs
Runway Fric Test	ASTM E1859	NA	Annually	MP		X	1,3	5+L Yrs
Inertial Profiler	ASTM E950	NA	Annually	MP		X	1,3	5+L Yrs
Properties								
Complex Modulus ****		NA	3 Times	Site 3 Locations[5]	X	X	3[5]	0,3,8 yrs
Impedance Tube	ASTM E1050	NA	3 Times	Site 3 Locations[5]	X	X	3[5]	0,3,8 yrs
Flow	ASTM C522	NA	3 Times	Site 3 Locations[5]	X	X	3[5]	0,3,8 yrs
Void Content	ASTM D3203	NA	3 Times	Site 3 Locations[5]	X	X	3[5]	0,3,8 yrs
Asphalt Content	ASTM D2172	NA	3 Times	Site 3 Locations[5]	X	X	3[5]	0,3,8 yrs
Gradation	ASTM C 136	NA	3 Times	Site 3 Locations[5]	X	X	3[5]	0,3,8 yrs
Environmental								
Weather Station		SA FF	SA FF		X	X	2,3	SA FF

** Site Type Number 1= Annual Test at Milepost in Travel Lane Lane of Each Roadway Direction
Site Type Number 2= Site Specific Location and Test Plan Approval Required
Site Type Number 3= Research Grade Site (Establishing Relationships between near/farfield)
-- Described in Site 2 or 3 Workplans, Respectfully

*** Before Testing would be consists of Passby Testing Using Controlled Fleet (Three Vehicle Types)
**** Includes Determination of Dynamic Modulus and Damping Coefficient

[5] At least one per construction project and at site three locations for:mix design stage,at 3 years,at 8 yrs
5 + L= Test Frequency will be modified after 5 yrs depending on results and continued for Service Life
3 + L= Test Frequency will be modified after 3 yrs depending on results
SA FF= Same As Far Field Testing

Appendix

Data Acquisition Plan

Copies of Applicable Test Procedures to be Included Later

Quiet Pavement Pilot Program
Appendix -
Data Acquisition Plan
05/14/03

1. **Introduction**

   The Quiet Pavement Pilot Program will evaluate the highway traffic noise reduction benefits gained from the use of various pavement types and/or textures. However, safety and durability remain the most important factors in pavement type and/or texture considerations. Accordingly, this data acquisition plan includes the collection of data not only related to highway traffic noise characteristics but also to the safety and durability aspects of the associated pavements. The plan is intended to collect data necessary to accomplish the following:

   a. Quantify the acoustic properties of new pavement as compared to existing pavement;
   b. Quantify the variation of pavement acoustic properties with age;
   c. Quantify variation of pavement acoustic properties with season;
   d. Determine the correlation (if any) between physical pavement characteristics (such as macrotexture, void content, impedance) and the pavement acoustic properties, so that acoustical performance can be determined by the physical observation of pavement; and
   e. (Optional) Determine the correlation between wayside and near-field acoustical measurements, so that near-field measurements alone may be used for future pavement noise evaluations.

2. **Data Collection**

   All data should be collected and analyzed in general conformance with *ANSI S12.8-1998 and ANSI S1.13-1995 and FHWA's procedures, Measurement of Highway-Related Noise (FHWA-PD-96-046).*

   a. Measurement sites must meet Reference Energy Mean Emission Level-type criteria including the following:
      i. Relatively flat terrain;
      ii. Free from reflective objects; and
      iii. Free from electromagnetic interference.
   b. Types of data to be collected include the following (the specifications for each data type are presented later in the plan):
      i. Wayside acoustical data;
      ii. Pavement data;
      iii. Traffic data;
      iv. Safety data;
      v. Meteorological data; and
      vi. (Optional) Near-field acoustical data *(required if near-field measurements are to be used to characterize pavements – must be*

accompanied by simultaneous wayside acoustical measurements [wayside measurements (measurements with stationary microphones) will be taken at Site 3 locations (research grade sites) and Site 2 locations (selected residence sites – approximately 18 locations for 6 projects)]

1. Acoustic intensity method
2. CPX trailer method (ISO 11819-2)

c. Before measurements begin, FHWA must approve the following information as submitted by ADOT:
   i. The location and description of all measurement sites; and
   ii. The measurement methodology, including specific instrumentation and procedures to be used.

3. Data Analysis

All data should be collected and analyzed in general conformance with ***ANSI S12.8-1998 and ANSI S1.13-1995 and FHWA's procedures, Measurement of Highway-Related Noise (FHWA-PD-96-046).***

a. Differences between measurement pairs (measurements made at different times at a single site, or at different sites) must be accounted for during analysis for the following:
   i. Traffic composition and speeds;
   ii. Meteorological conditions; and
   iii. Site characteristics, such as ground cover.

b. Analysis must include sufficient data to represent typical traffic composition and speed, as well as the variation in expected meteorological conditions for the subject area.

4. Development of a Pavement Adjustment Factor Based Upon Ongoing Measurements

a. At least one day of measurements is required to obtain enough data to calculate an adjustment factor for a single site under one set of conditions (this may not apply to the existing traffic pass-by method, where more than one day of measurements may be required in order to obtain a sufficient amount of data). This requires:
   i. 6 hours for continuous flow; or
   ii. The number of hours it takes to collect the minimum number of clean pass-by events.

b. To obtain an overall adjustment factor, a minimum of three sites is needed, with data collected over time and in different seasons, such that the expected ranges of conditions (for traffic composition and speeds, meteorological conditions, and site characteristics) for the subject area are included in the measurements.

5. Wayside Acoustical Data

a. Measurement Methods (there are three possible types; the choice of type is made based upon the possibility of road closures, density of traffic, etc.):

i. Continuous Flow
1. Measure time-averaged sound levels (15 min, L_{Aeq}); and
2. Traffic must be constant and heavy enough for uninterrupted data blocks and must be representative of composition and speeds typical of subject area.

ii. Controlled Pass-Bys
1. Measure L_{Amax} for each vehicle;
2. Number of pass-bys must meet the criteria for the statistical pass-by method (SPB; ISO 11819-1); and
3. Apply the SPB to get the statistical pass-by index (SPBI).

iii. Existing Traffic Pass-Bys
1. Measure L_{Amax} for each vehicle;
2. Number of pass-bys must meet the criteria for the statistical pass-by method (SPB; ISO 11819-1); and
3. Apply the SPB to get the statistical pass-by index (SPBI).

b. Data Collection

i. Microphone Position(s)
1. Required location: distance of 50 ft from the center of the near travel lane, height 5 ft above the ground; and
2. Optional locations: distance 50 ft, height 15 ft; distance 25ft, height 5 ft.

ii. Collection Requirements
1. Sound levels (L_{Aeq}, L_{Amax}), as specified in section 5.a (Measurement Methods);
2. One-third octave-band *data (ANSI/ISO Bands 17 through 40, nominal frequencies of 50 Hz through 10 kHz)* – a spectrum analyzer must be used either directly in the field, or later with recorded data; and
3. Acoustic data must be recorded (DAT recorder).

iii. Equipment Specifications
1. Microphones and sound level meters must conform to ANSI S1.4 Type 1;
2. Spectrum analyzers must conform to *ANSI S1.11 Type 2 (or IEC 61260 Class 2), and*
3. FHWA must approve all instrumentation prior to its use.

6. <u>Pavement Data</u>

a. Collection Requirements

i. Obtain pavement specifications for construction (construction date, mix design, pavement thickness, etc.) for:
1. Existing pavement (as a minimum, identify the approximate age, general type, and texture specified for the pavement); and
2. New pavement.

ii. Measure actual pavement properties of new construction (not as stated in specifications):

1. Macrotexture (use core samples, ROSAN, or other method); document the (1) Mean Texture Depth (MTD) ASTM E-965; and (2) Mean Profile Depth (MPD) ASTM E-2157-01 or ASTM E-1845/ISO 13473 [Note: The CT Meter will be used to measure surface texture];
2. Void content, if possible (use core samples or other method;
3. Pavement temperature measured periodically, at least once each hour (preferably once for each pass-by when implementing one of the pass-by methods); and
4. (Optional) Acoustic impedance of the pavement.

7. Traffic Data
   a. Measurement Methods (type dependent on acoustical measurement type and available staff/equipment):
      i. Record all vehicles with a video camera and extract information at a later time (for continuous flow traffic or single vehicle pass-bys); or
      ii. Log all traffic information (for single vehicle pass-bys).
   b. Collection Requirements – collect the following information during all acoustical measurements:
      i. Vehicle type in 5 categories (automobile, medium truck, heavy truck, bus, and motorcycle); and
      ii. Vehicle speeds
         1. Pass-by method: speed for each vehicle
         2. Continuous flow method: average speeds during specified time blocks
         3. Traffic speeds can be measured using traffic cones for timing, radar, pneumatic line, etc. (note: speed measurement methods must not interfere with acoustic data collection or influence driver behavior).

8. Safety Data

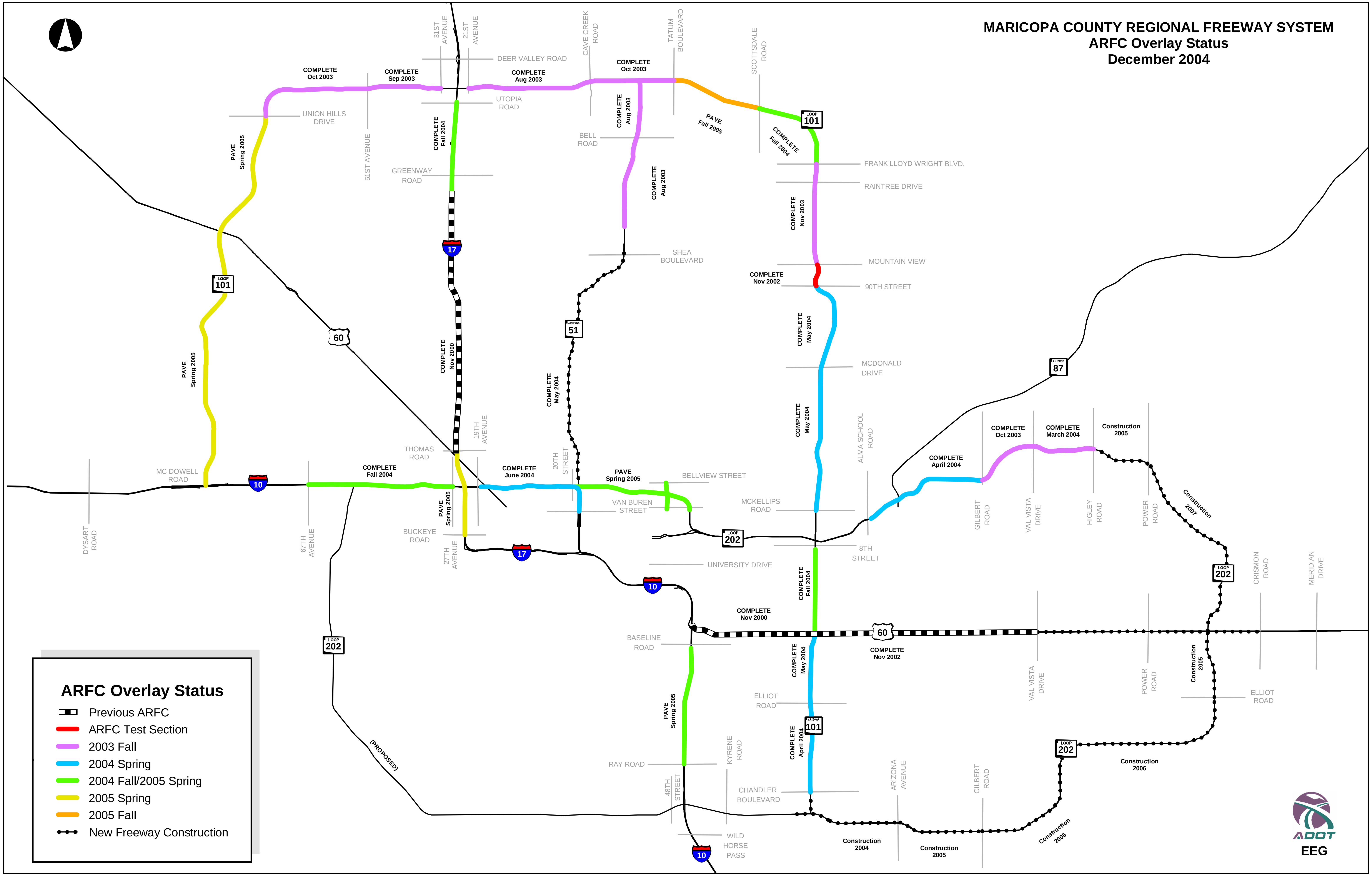
ARFC is not an experimental surface. ADOT has 20 years of safety data on ARFC on file for inspection. No safety data collection will be part of this pilot program.

9. Meteorological Data
   a. Meteorological Sensor Location(s)
      i. Must be close enough to the microphone location so that weather measurements represent conditions at the microphone
   b. Collection Requirements – collect the following during all acoustical measurements (continuous for continuous flow traffic and during each event for single vehicle pass-bys):
      i. Air temperature;
      ii. Wind speed;

iii. Wind direction; and
iv. Relative humidity.

APPENDIX 2

Regional Freeway Map



MARICOPA COUNTY REGIONAL FREEWAY SYSTEM
ARFC Overlay Status
December 2004
ARFC Overlay Status
Previous ARFC
ARFC Test Section
2003 Fall
2004 Spring
2004 Fall/2005 Spring
2005 Spring
2005 Fall
New Freeway Construction
COMPLETE Oct 2003
COMPLETE Sep 2003
COMPLETE Aug 2003
COMPLETE Oct 2003
PAVE Fall 2005
COMPLETE Fall 2004
COMPLETE Fall 2004
COMPLETE Aug 2003
COMPLETE Aug 2003
PAVE Spring 2005
PAVE Spring 2005
COMPLETE Nov 2003
COMPLETE Nov 2002
COMPLETE May 2004
COMPLETE Nov 2000
COMPLETE May 2004
COMPLETE May 2004
COMPLETE Fall 2004
COMPLETE June 2004
PAVE Spring 2005
PAVE Spring 2005
COMPLETE Oct 2003
COMPLETE March 2004
Construction 2005
COMPLETE April 2004
Construction 2007
COMPLETE Fall 2004
COMPLETE Nov 2000
COMPLETE Nov 2002
COMPLETE May 2004
PAVE Spring 2005
COMPLETE April 2004
Construction 2005
Construction 2006
Construction 2004
Construction 2005
Construction 2006
(PROPOSED)
DEER VALLEY ROAD
UTOPIA ROAD
UNION HILLS DRIVE
BELL ROAD
GREENWAY ROAD
FRANK LLOYD WRIGHT BLVD.
RAINTREE DRIVE
MOUNTAIN VIEW
90TH STREET
SHEA BOULEVARD
MCDONALD DRIVE
THOMAS ROAD
MC DOWELL ROAD
BELLVIEW STREET
VAN BUREN STREET
MCKELLIPS ROAD
BUCKEYE ROAD
8TH STREET
UNIVERSITY DRIVE
BASELINE ROAD
ELLIOT ROAD
ELLIOT ROAD
RAY ROAD
CHANDLER BOULEVARD
WILD HORSE PASS
31ST AVENUE
21ST AVENUE
CAVE CREEK ROAD
TATUM BOULEVARD
SCOTTSDALE ROAD
51ST AVENUE
19TH AVENUE
20TH STREET
DYSART ROAD
67TH AVENUE
27TH AVENUE
ALMA SCHOOL ROAD
GILBERT ROAD
VAL VISTA DRIVE
HIGLEY ROAD
POWER ROAD
CRISMON ROAD
MERIDIAN DRIVE
VAL VISTA DRIVE
POWER ROAD
KYRENE ROAD
48TH STREET
ARIZONA AVENUE
GILBERT ROAD
101
17
51
60
87
10
202
ADOT
EEG

APPENDIX 3

Noise Technical Study Report:
ARFC Test Section

NOISE STUDY TECHNICAL REPORT

Roadway Insertion Loss Noise Measurements
Rubberized Asphalt Overlay
Scottsdale, Arizona

FINAL

Prepared For:
City of Scottsdale
7447 East Indian School Road
Scottsdale, Arizona 85252

Prepared by:
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701 West Southern Avenue- Suite 105
Mesa, Arizona 85210

JANUARY 2002

TABLE OF CONTENTS

EXECUTIVE SUMMARY

This study measured the noise levels from several roadways within the City of Scottsdale before and after a Rubberized Asphalt Concrete (RAC) overlay to evaluate the noise attenuation properties of the RAC pavement versus the conventional asphalt pavement.

The study was conducted on five roadway segments within the City, which were selected from the pre-established schedule of pavement overlays to represent a variety of traffic speed and operational characteristics. Roadway designations of the segments selected for the study ranged from major arterials to residential collectors, with speed limits from 30 miles per hour (mph) to 45 mph. The roadways included segments of Via Linda, Shea Boulevard, 68th Street, Thomas Road, and 90th Street.

"Before" measurements were conducted between September 6 and September 18, 2001. The pavement overlays were conducted between late September and early November. "After" measurements were conducted on three of the roadway segments between October 16 and October 17, 2001. Two of the roadway segments were monitored on December 19, 2001 because of delays in the overlay schedule and continual weather conditions that prevented valid follow-up readings through November and early December.

Measurement events consisted of a series of three 15-minute noise measurements within a one-hour period. Traffic volumes were recorded during the entire one-hour measurement period. Because of variations in the traffic volume and vehicle mix between the "before" and "after" measurement periods, adjustments were made to the "after" noise levels to normalize for the traffic differences.

The noise level at each of the five roadway sites was lower during the "after" measurements than during the "before" measurements. After adjusting the "after" noise level for differences in traffic volume and vehicle mix between the two monitoring events, the noise levels remained lower during the "after" conditions. Adjusted "after" noise levels ranged between 2.5 and 5.1 decibels lower than the "before" noise levels, with four of the five locations between 2.5 and 3.4 decibels.

In summary, noise levels on the five roadway segments in Scottsdale ranged from 3 to 5 decibels lower with the RAC overlay than with the previous conventional asphalt pavement. The median roadway insertion loss was 3 decibels.

1.1 PURPOSE AND SCOPE

The purpose of this Noise Study Technical Report (Noise Report) is to present the results of a Roadway Insertion Loss Noise Measurement study performed for the Rubberized Asphalt Concrete (RAC) overlay maintenance program in Scottsdale, Arizona. The program consists of overlaying conventional asphalt roadways with RAC pavement as part of a normal maintenance program. RAC pavement has been widely recognized as having favorable maintenance characteristics and is becoming recognized as having measurable noise attenuation properties. This study measured the noise levels from several roadways within the City before and after the overlay to evaluate the noise attenuation properties of the RAC pavement.

The intent of this study was not to obtain representative noise levels at sensitive receiver locations along the various roadway segments. The monitoring locations were placed close to the roadway with no obstructions between the noise meter and the roadway. The goal was to minimize influences from noise attenuating structures or other neighborhood noise sources and attempt to isolate the roadway noise source. Consequently, the noise levels recorded at each of the monitoring sites are higher than would be observed at a sensitive noise receiver location, such as a residential backyard. The noise levels in this report should not be construed to be representative of the typical noise levels in the surrounding neighborhood.

1.2 ROADWAY SEGMENT DESCRIPTIONS

The study was conducted on five roadway segments within the City of Scottsdale. The roadways were selected by the City from the pre-established schedule of pavement overlays to represent a variety of traffic speed and operational characteristics. Roadway designations of the segments selected for the study range from major arterials to residential collectors. Speed limits range from 30 miles per hour (mph) to 45 mph. Refer to Appendix A for aerial photographs of the monitoring locations for each of the five roadway segments.

Via Linda between Shea Boulevard and Frank Lloyd Wright Boulevard consists of two travel lanes in each direction with a raised landscaped median and intermittent left turn bays. The posted speed limit on Via Linda is 35 mph and truck traffic is minimal, as Via Linda is designated a minor arterial in this area. The monitoring location was placed at the northeast corner of Via Linda and 108th Street, approximately 23 feet from the back edge of the sidewalk on Via Linda.

90th Street between Cactus Road and Sweetwater Avenue consists of one lane in each direction separated by a double-yellow centerline. The posted speed limit on 90th Street is 30 mph and truck traffic is very minimal, since 90th Street is a residential collector street in this area. The monitoring location was placed on the east side of 90th Street, near the retention basin south of Carol Way, approximately 5 feet from the back edge of the sidewalk.

Shea Boulevard between Hayden Road and Pima Freeway consists of three lanes in each direction with a raised landscaped median and intermittent left turn bays. The posted speed limit is 45 mph with heavy truck traffic. Shea Boulevard is designated as a major arterial. The monitoring location was placed on the south side of Shea Boulevard, west of 82nd Place, approximately 29 feet from the back edge of the sidewalk.

68th Street between McDowell Road and Continental Drive (Roosevelt Street) consists of one lane in each direction with a two-way center left turn lane. The posted speed limit on 68th Street is 35 mph with minimal truck traffic, as 68th Street is a residential collector street. The pre-overlay monitoring location was placed on the east side of 68th Street, in the alley between Belleview Street and Moreland Street, approximately 8 feet from the back edge of the sidewalk. The monitoring location was moved for the post-overlay reading, due to a barking dog in the yard immediately adjacent to the pre-overlay monitoring location. The post-overlay monitoring location was placed on the west side of 68th Street, in the alley between Belleview Street and Moreland Street, approximately 8 feet from the back edge of the sidewalk. The two monitoring locations are equivalent.

Thomas Road between 64th Street and 68th Street consists of two lanes westbound and three lanes eastbound, with a two-way center left turn lane. The posted speed limit is 40 mph with moderate truck traffic. Thomas Road is designated as a minor arterial in this area. The monitoring location was placed on the south side of Thomas Road, between 64th Street and 68th Street, approximately 35 feet from the back edge of a utility pole in the sidewalk.

2.1 PROCEDURES

The noise measurements for this study followed the procedures outlined in publication FHWA-PD-96-046, "Measurement of Highway-Related Noise", specifically the "direct" BEFORE/AFTER measurements described in Section 6. The guidance details procedures for barrier insertion loss measurements rather than pavement-type change measurements, however, the result is a comparison of the noise levels before and after a physical change in the site geometry. Therefore, the procedure was deemed the most beneficial for this study.

The measurement procedure consisted of collecting a series of noise measurements of the "before" condition, prior to the RAC overlay. Exact monitoring site locations were documented, as well as meteorological conditions and other noise sources. Traffic volumes were videotaped during the monitoring and were later counted with vehicle assignment to categories by vehicle type.

Following the RAC overlay, the noise measurements were repeated at the exact locations of the earlier monitoring to obtain the "after" conditions. An exception was the 68th Street site, where the monitoring location was moved to an equivalent location on the opposite side of the street for the "after" conditions monitoring. Meteorological conditions and other noise sources were documented and traffic conditions were videotaped.

Noise levels were recorded as L_{Aeq1h}, which is the equivalent loudness over a 1-hour period using the A-weighted decibel scale (dBA). This measure is the standard for traffic noise measurements and represents an integrated noise level over the measurement period.

2.2 MEASUREMENT EVENTS

"Before" measurements were conducted between September 6 and September 18, 2001. The Via Linda and Shea Boulevard sites were monitored on September 6, the 68th Street and Thomas Road sites were monitored on September 11, and the 90th Street site was monitored on September 18.

"After" measurements were conducted on three of the roadway segments between October 16 and October 17, 2001. Two of the roadway segments were monitored on December 19, 2001 because of delays in the overlay schedule and continual weather conditions that prevented valid follow-up readings through November and early December. The Via Linda and Shea Boulevard sites were monitored on October 16, and the 90th Street site was monitored on October 17. The 68th Street and Thomas Road sites were monitored on December 19.

Days and times of the measurement events were selected with the assistance of the City of Scottsdale Transportation Department. The measurement events were limited to Tuesday through Thursdays, since weekend days, Mondays and Fridays tend to exhibit unpredictable traffic conditions. The selected measurement times coincided with morning peak and mid-day off-peak traffic conditions, when those conditions were consistently replicable and did not result in deterioration of the Level of Service (LOS) to below LOS C conditions. Conditions of LOS A through LOS C are preferred for traffic noise measurements, since the traffic has not experienced congestion-related slowing.

Measurement events consisted of a series of three 15-minute noise measurements within a one-hour period. Traffic volumes were recorded during the entire one-hour measurement period. For most of the measurement sites, the first measurement was started one minute after the start of the one-hour measurement period. The second reading was started four minutes after the end of the first reading, and the third reading was started approximately five minutes after the end of the second reading. The third reading concluded five minutes prior to the end of the one-hour measurement period.

2.3 OTHER NOISE SOURCES

During the measurements, the major noise source was noted in the field notes, along with other sources of environmental noise that may contribute to the actual noise level being recorded. Other noise sources included airplanes, local activity, landscaping equipment, birds and insects, etc. For each of the monitoring periods, the major noise source was traffic on the street being monitored, with other noise sources contributing a minimal amount to the overall noise level. Therefore, other noise sources were disregarded in the comparison of "before" and "after" noise measurements.

The only significant issue was with the "before" readings on 68th Street and Thomas Road, which were conducted on the morning of September 11 between 7:00 am and 11:00 am. During this time, the Federal Aviation Administration (FAA) had ordered an emergency grounding of all aviation traffic nationwide. No airplanes were observed during the monitoring period at either location. During the "after" readings, between seven and 13 airplanes were observed during each 15-minute monitoring period at the 68th Street site, and between two and four airplanes were observed during each 15-minute monitoring period at the Thomas Road site. This difference in air traffic conditions would result in the "after" readings being slightly higher than the "before" conditions, given equivalent traffic, meteorological and pavement conditions, although the difference would only be about two or three tenths of a decibel. Since this difference would tend slightly to underestimate the amount of noise attenuation provided by the RAC pavement, which would err on the side of conservatism, no correction was made in the data analysis for this difference.

2.4 METEOROLOGICAL CONDITIONS

Meteorological conditions were recorded at the start of each of the 15-minute readings during the "before" and "after" measurements. According to FHWA-PD-96-046, the meteorological conditions of the "before" and "after" conditions should be equivalent for valid comparisons of the two measurement events. Meteorological conditions, including cloud cover, temperature, humidity, wind speed and wind direction were recorded in the field logs. During the "after" measurements, the meteorological conditions were compared to the "before" measurements to ensure equivalence. If meteorological equivalence could not be ensured during the "after" reading, the measurement event would have been terminated and re-scheduled to another day.

Meteorological equivalence is determined by comparing the "before" and "after" conditions for each of the parameters. The cloud cover is classified based on percentages with daytime classification from Class 1 (greater than 80% obscured) to Class 3 (less than 20% obscured). Nighttime classifications are also included as Class 4 (less than 50% cover) and Class 5 (greater than 50% cover). "Before" and "after" cloud cover classifications should be the same to be deemed equivalent.

"Before" and "after" temperatures are deemed equivalent if they are within 14°C (25.2°F). Relative humidity should be similar, according to the FHWA guidance. "Before" and "after" wind speed should be within 2.2 mph and the wind direction should be similar to be deemed equivalent.

At the Via Linda site, the "before" measurement meteorological conditions included clear skies (Class 3), temperature ranging from 77.7 to 79.3 °F, humidity from 38 to 43 %, and winds ranging from calm to 1.7 mph from the East. "After" conditions consisted of clear skies (Class 3), temperature ranging from 71.6 to 73.0 °F, humidity from 23 to 24 %, and winds from 1.0 to 1.7 mph from the East. As a result, the meteorological conditions of the "before" and "after" readings are deemed equivalent at this measurement site.

At the 90th Street site, the "before" measurement meteorological conditions included clear skies (Class 3), temperature ranging from 84.6 to 86.0 °F, humidity from 27 to 28 %, and winds ranging from calm to 0.7 mph from a variable direction. "After" conditions consisted of mostly clear skies (Class 3), temperature ranging from 76.6 to 79.7 °F, humidity of 27 %, and winds ranging from calm to 1.1 mph from a variable direction. As a result, the meteorological conditions of the "before" and "after" readings are deemed equivalent at this measurement site.

At the Shea Boulevard site, the "before" measurement meteorological conditions included clear skies (Class 3), temperature ranging from 83.8 to 86.0 °F, humidity ranging from 32 to 36 %, and winds from 0.8 mph from a variable direction to 1.3 mph from the East. "After" conditions consisted of clear skies (Class 3), temperature ranging from 72.3 to 76.6 °F, humidity from 25 to 30 %, and winds ranging from 1.2 to 1.7 mph from the East. As a result, the meteorological conditions of the "before" and "after" readings are deemed equivalent at this measurement site.

At the 68th Street site, the "before" measurement meteorological conditions included clear skies (Class 3), temperature ranging from 80.3 to 81.9 °F, humidity ranging from 29 to 33 %, and winds ranging from calm to 0.5 mph from a variable direction. The "after" monitoring was delayed because of cold and wet weather conditions throughout November that prevented valid comparison measurements. "After" conditions consisted of clear skies (Class 3), temperature ranging from 57.9 to 64.8 °F, humidity ranging from 27 to 34 %, and winds ranging from calm to 2.5 mph from the East. As a result, the meteorological conditions of the "before" and "after" readings are deemed equivalent at this measurement site.

At the Thomas Road site, the "before" measurement meteorological conditions included clear skies (Class 3), temperature ranging from 92.5 to 94.5 °F, humidity ranging from 26 to 28 %, and winds ranging from 4.3 to 6.0 mph from the East. The "after" monitoring was delayed because of cold and wet weather conditions throughout November that prevented valid comparison measurements. "After" conditions consisted of clear skies (Class 3), temperature ranging from 70.9 to 71.1 °F, humidity ranging from 21 to 22 %, and winds ranging from 3.2 to 4.6 mph from the East. As a result, the meteorological conditions of the "before" and "after" readings are deemed equivalent at this measurement site.

2.5 MEASUREMENT RESULTS

Three individual 15-minute noise measurements were collected at each of the five locations for both the "before" and "after" overlay conditions. The three readings varied somewhat based on fluctuations in traffic volume during the measurement period. The three readings were averaged together to calculate the average noise level over the entire one-hour measurement period. Variations in traffic volume between the one-hour "before" measurement period and the one-hour "after" measurement period accounted for some of the difference in the noise levels at each of the sites. Adjustments to the noise levels to correct for traffic variations are discussed in Section 3 of this report. Table 1 displays a summary of the Uncorrected Results.

Table 1 – Uncorrected Results			
Site Location	**"Before" (L_{Aeq1h})**	**Uncorrected "After" (L_{Aeq1h})**	**Reduction (dBA)**
Via Linda	64.7	59.0	5.7
90th Street	65.4	60.8	4.6
Shea Boulevard	68.3	65.2	3.1
68th Street	67.5	64.5	3.0
Thomas Road	66.0	64.2	1.8

At the Via Linda site, the average "before" noise level was 64.7 L_{Aeq1h}, with a range of 63.2 to 66.5 L_{Aeq1h}. The higher reading was the result of several school busses and larger trucks during the second of the three readings. After the new pavement overlay was placed, the average "after" noise level was 59.0 L_{Aeq1h}, with a range of 57.9 to 59.8 L_{Aeq1h}. Traffic volumes during the "after" monitoring period were lower than during the "before" monitoring period. Without adjusting for differences in traffic volume between the two monitoring events, the "after" noise level is 5.7 decibels lower than the "before" noise level.

At the 90th Street site, the average "before" noise level was 65.4 L_{Aeq1h}, with a range of 64.9 to 65.8 L_{Aeq1h}. The average "after" noise level was 60.8 L_{Aeq1h}, with a range of 60.2 to 61.4 L_{Aeq1h}. Traffic volumes during the two measurement periods were similar. Without adjusting for slight differences in traffic volume between the two monitoring events, the "after" noise level is 4.6 decibels lower than the "before" noise level.

At the Shea Boulevard site, the average "before" noise level was 68.3 L_{Aeq1h}, with a range of 68.1 to 68.7 L_{Aeq1h}. The average "after" noise level was 65.2 L_{Aeq1h}, with a range of 65.0 to 65.6 L_{Aeq1h}. Traffic volumes during the two measurement periods were similar. Without adjusting for slight differences in traffic volume between the two monitoring events, the "after" noise level is 3.1 decibels lower than the "before" noise level.

At the 68th Street site, the average "before" noise level was 67.5 L_{Aeq1h}, with a range of 67.1 to 67.8 L_{Aeq1h}. The average "after" noise level was 64.5 L_{Aeq1h}, with a range of 64.1 to 65.3 L_{Aeq1h}. Traffic volumes during the "after" monitoring period were lower than during the "before" monitoring period. Without adjusting for differences in traffic volume between the two monitoring events, the "after" noise level is 3.0 decibels lower than the "before" noise level.

At the Thomas Road site, the average "before" noise level was 66.0 L_{Aeq1h}, with a range of 65.9 to 66.0 L_{Aeq1h}. The average "after" noise level was 64.2 L_{Aeq1h}, with a range of 63.9 to 64.5 L_{Aeq1h}. Traffic volumes during the "after" monitoring period were higher than during the "before" monitoring period, although truck volumes were similar between the two monitoring periods. Without adjusting for differences in traffic volume between the two monitoring events, the "after" noise level is 1.8 decibels lower than the "before" noise level.

Overall, the noise levels within each one-hour measurement period were very consistent. For most of the measurement periods, the range of the three noise levels was less than one decibel. The exception was the Via Linda site, which had a range of 3.3 decibels during the "before" conditions and 1.9 decibels during the "after" conditions. Short-term fluctuations in the traffic volume and mix of vehicles during the one-hour period accounted for the range in noise levels for this roadway.

SECTION 3 – DATA ANALYSIS

3.1 METHODS

Some of the difference in the "before" and "after" noise level measurements is the result of variations in traffic volume and vehicle mixture between the two measurement events. To adjust for these traffic differences, a correction was made using a procedure developed by the California Department of Transportation (CALTRANS) in their *Technical Noise Supplement, A Technical Supplement to the Traffic Noise Analysis Protocol*, October 1998. The procedure is detailed in Section N-3340, "Normalizing Measurements for Differences in Traffic Mixes and Volumes". Although the procedure was developed for use in California, it represents a widely accepted methodology for adjusting for traffic variations and is based on extensive research by CALTRANS.

The methodology converts truck volume into an equivalent automobile volume to derive the total vehicle equivalent volume. Conversion factors are based on travel speed and represent the amount of noise produced by trucks as compared to automobiles. Once the total vehicle equivalent volume is calculated for the "before" and "after" conditions, adjustments can be made to the noise level based on simple logarithmic calculations.

3.2 NOISE LEVEL ADJUSTMENTS

The traffic volumes for the "before" and "after" conditions for each of the five roadways were converted into vehicle equivalent volumes for direct comparison purposes. Based on the traffic comparison, a correction factor was applied to the uncorrected "after" noise level to obtain the corrected "after" noise level, which was compared to the "before" noise level. Table 2 displays a summary of the Corrected Results. Refer to Appendix B for detailed calculations sheets for each of the five roadways.

Table 2 – Corrected Results

Site Location	"Before" (L_{Aeq1h})	Uncorrected "After" (L_{Aeq1h})	Correction Factor (dBA)	Corrected "After" (L_{Aeq1h})	Reduction (dBA)
Via Linda	64.7	59.0	+2.3	61.3	3.4
90th Street	65.4	60.8	-0.5	60.3	5.1
Shea Boulevard	68.3	65.2	+0.4	65.6	2.7
68th Street	67.5	64.5	+0.5	65.0	2.5
Thomas Road	66.0	64.2	-0.9	63.3	2.7

At the Via Linda site, traffic volumes during the "before" measurements were substantially higher than during the "after" measurements. The vehicle equivalent volume was 1,117 vehicles during the "before" measurements and 660 vehicles during the "after" measurements. Calculating the logarithmic difference between the two volumes results in a correction factor of 2.3, which is added to the "after" noise level of 59.0 to obtain the adjusted "after" noise level. Comparing the "before" noise level of 64.7 decibels with the adjusted "after" noise level of 61.3 decibels results in a difference of 3.4 decibels.

At the 90th Street site, traffic volumes during the "before" measurements were slightly lower than during the "after" measurements. The vehicle equivalent volume was 501 vehicles during the "before" measurements and 568 vehicles during the "after" measurements. Calculating the logarithmic difference between the two volumes results in a correction factor of –0.5, which is added to the "after" noise level of 60.8 to obtain the adjusted "after" noise level. Comparing the "before" noise level of 65.4 decibels with the adjusted "after" noise level of 60.3 decibels results in a difference of 5.1 decibels.

At the Shea Boulevard site, traffic volumes during the "before" measurements were approximately equal to the "after" measurements, but contained a higher heavy truck volume. The vehicle equivalent volume was 4,099 vehicles during the "before" measurements and 3,773 vehicles during the "after" measurements. Calculating the logarithmic difference between the two volumes results in a correction factor of 0.4, which is added to the "after" noise level of 65.2 to obtain the adjusted "after" noise level. Comparing the "before" noise level of 68.3 decibels with the adjusted "after" noise level of 65.6 decibels results in a difference of 2.7 decibels.

At the 68th Street site, traffic volumes during the "before" measurements were slightly higher than during the "after" measurements. The vehicle equivalent volume was 907 vehicles during the "before" measurements and 800 vehicles during the "after" measurements. Calculating the logarithmic difference between the two volumes results in a correction factor of 0.5, which is added to the "after" noise level of 64.5 to obtain the adjusted "after" noise level. Comparing the "before" noise level of 67.5 decibels with the adjusted "after" noise level of 65.0 decibels results in a difference of 2.5 decibels.

At the Thomas Road site, traffic volumes during the "before" measurements were somewhat lower than during the "after" measurements, although truck volumes were similar. The vehicle equivalent volume was 2,375 vehicles during the "before" measurements and 2,941 vehicles during the "after" measurements. Calculating the logarithmic difference between the two volumes results in a correction factor of –0.9, which is added to the "after" noise level of 64.2 to obtain the adjusted "after" noise level. Comparing the "before" noise level of 66.0 decibels with the adjusted "after" noise level of 63.3 decibels results in a difference of 2.7 decibels.

SECTION 4 – RESULTS AND CONCLUSION

The noise level at each of the five roadway sites was lower during the "after" measurements than during the "before" measurements. After adjusting the "after" noise level for differences in traffic volume and vehicle mix between the two monitoring events, the noise levels remained lower during the "after" conditions. Adjusted "after" noise levels ranged between 2.5 and 5.1 decibels lower than the "before" noise levels, with four of the five locations between 2.5 and 3.4 decibels.

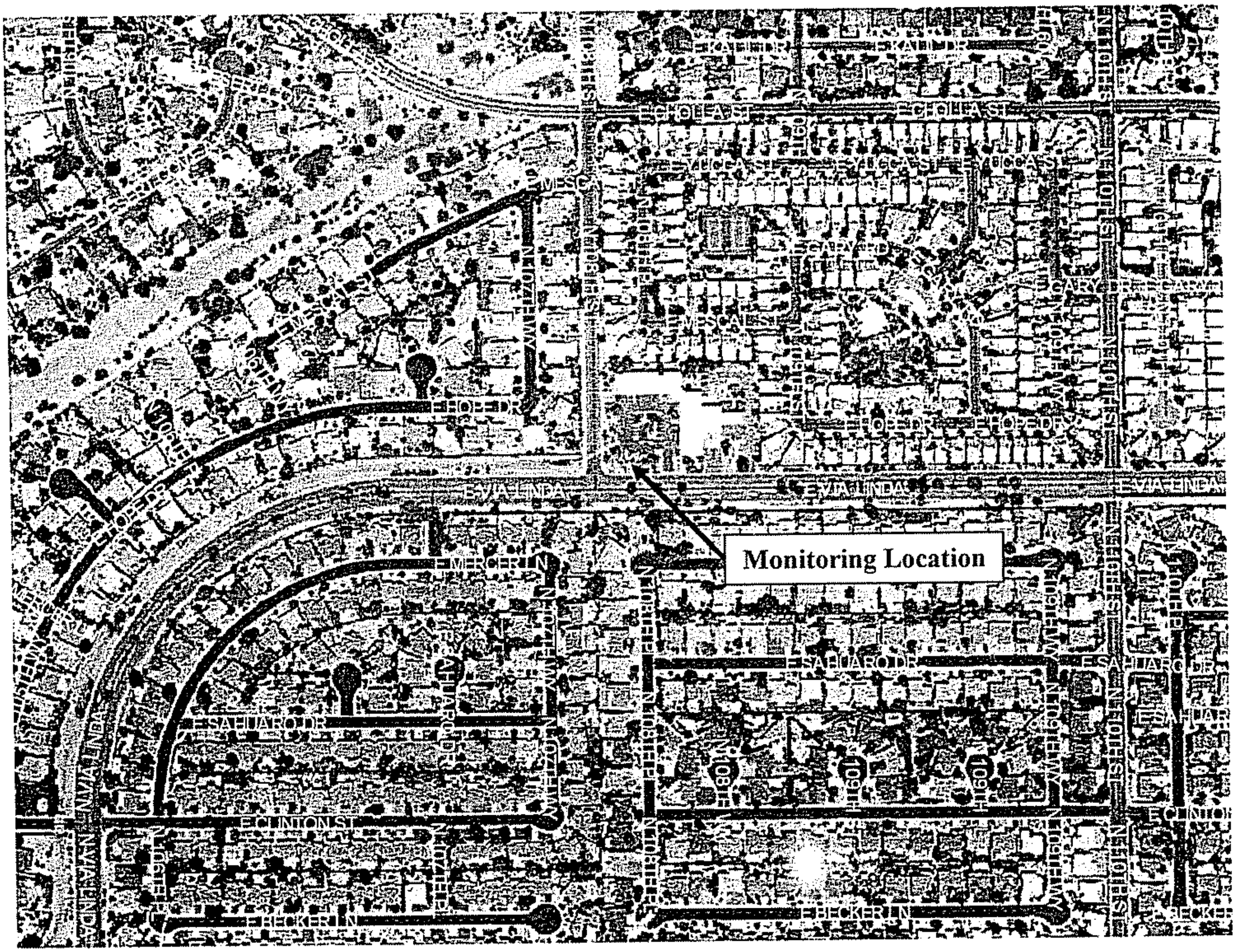
This 3 to 5 decibel reduction range is consistent with other published studies and Higgins & Associates' experience with similar studies when a conventional asphalt roadway is re-paved with a rubberized asphalt overlay. Had the existing pavement been concrete, the noise reduction from a rubberized asphalt overlay would have been higher, likely in the range of 5 to 8 decibels, based on other studies.

The noise reduction benefits of rubberized asphalt pavement demonstrated by this study represent the initial reduction provided by a newly-installed pavement overlay. To evaluate the long-term noise attenuation benefits, follow-up noise studies should be conducted periodically over time. An annual study at the same five monitoring locations would most effectively demonstrate the long-term performance of the rubberized asphalt pavement.

With the rubberized asphalt overlay, noise levels on the five roadway segments in Scottsdale ranged from 3 to 5 decibels lower than with the previous asphalt pavement. The median roadway insertion loss was 3 decibels.

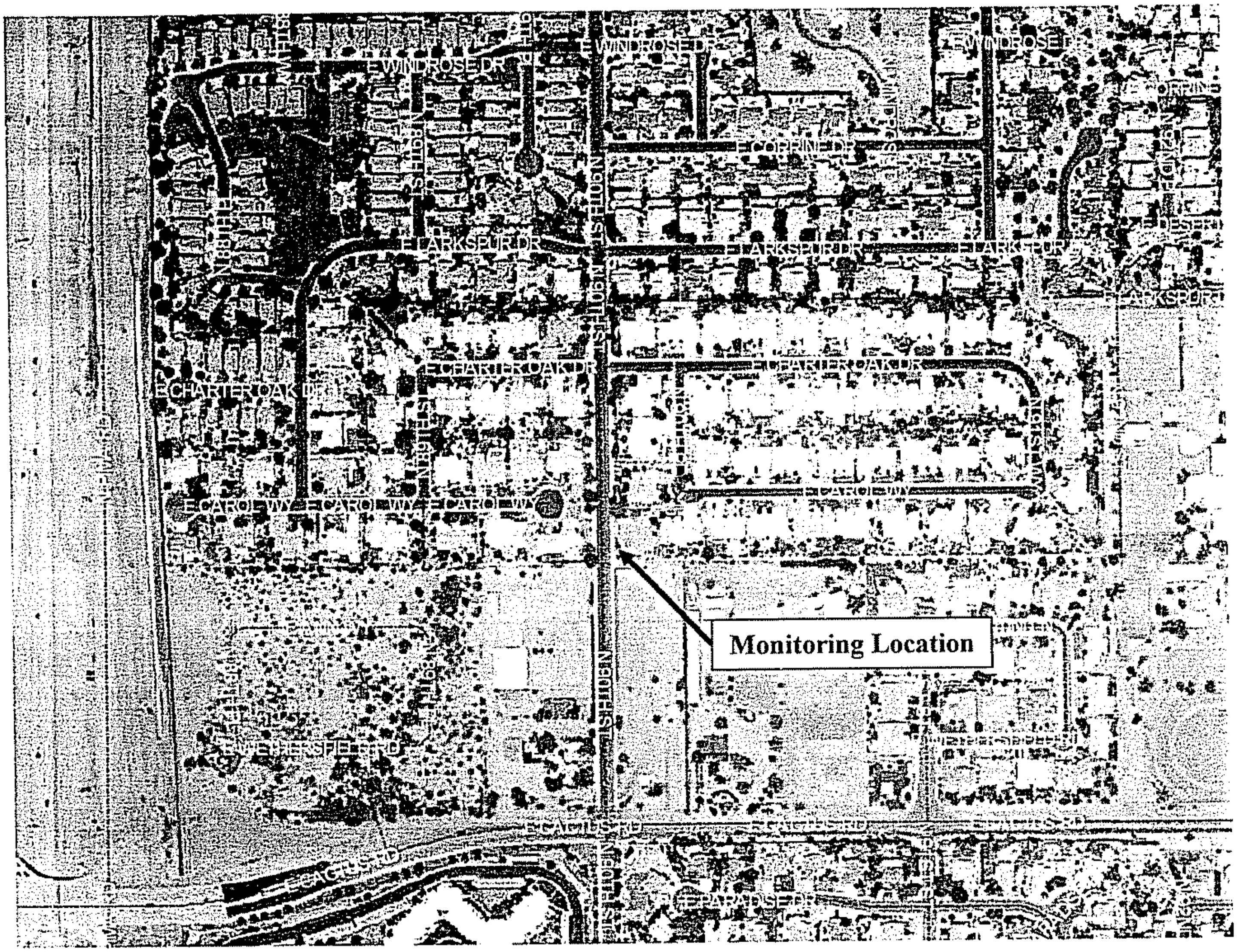
APPENDIX A

MONITORING LOCATIONS



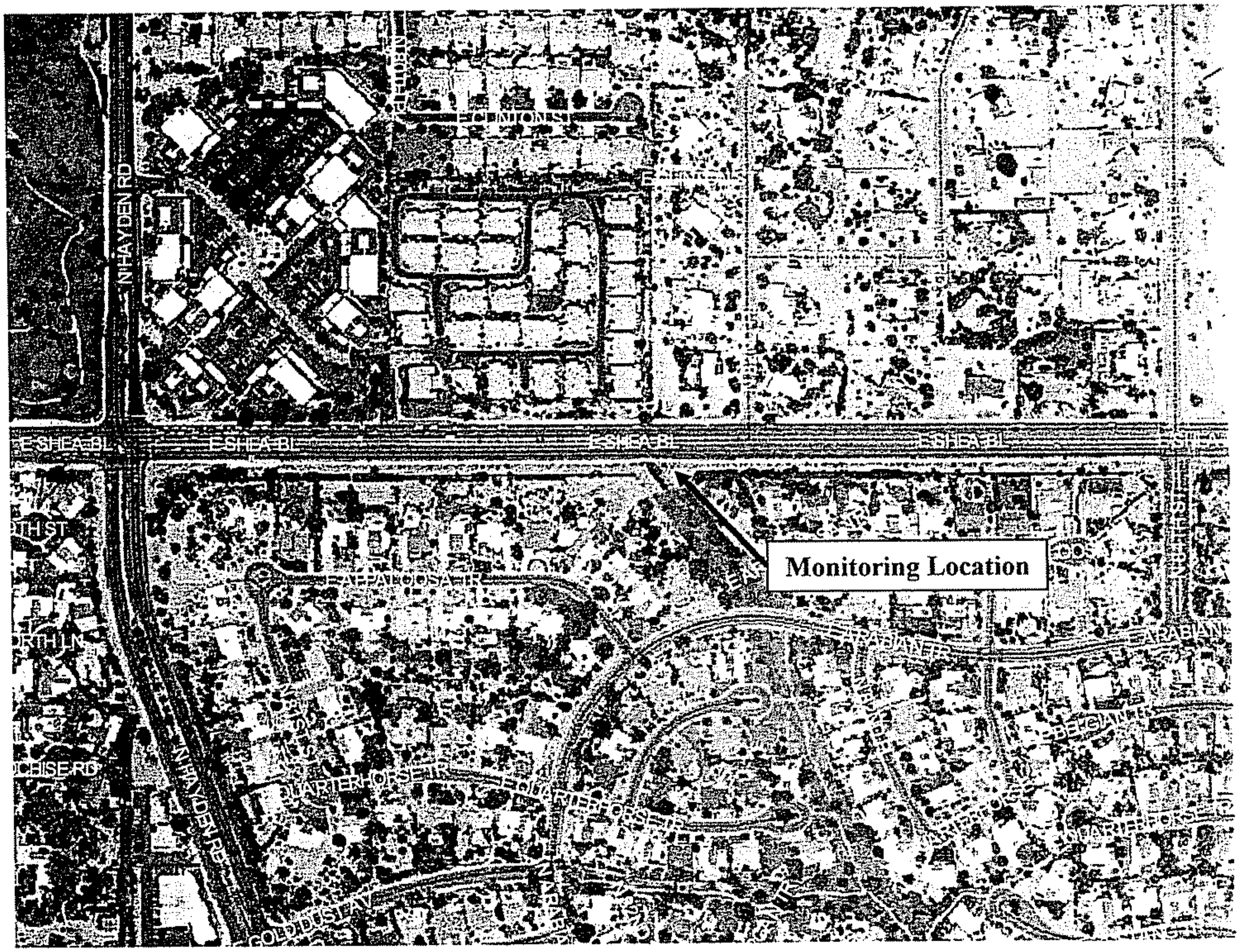
APPENDIX A
SHEET 1 OF 5

VIA LINDA SITE
MONITORING LOCATION



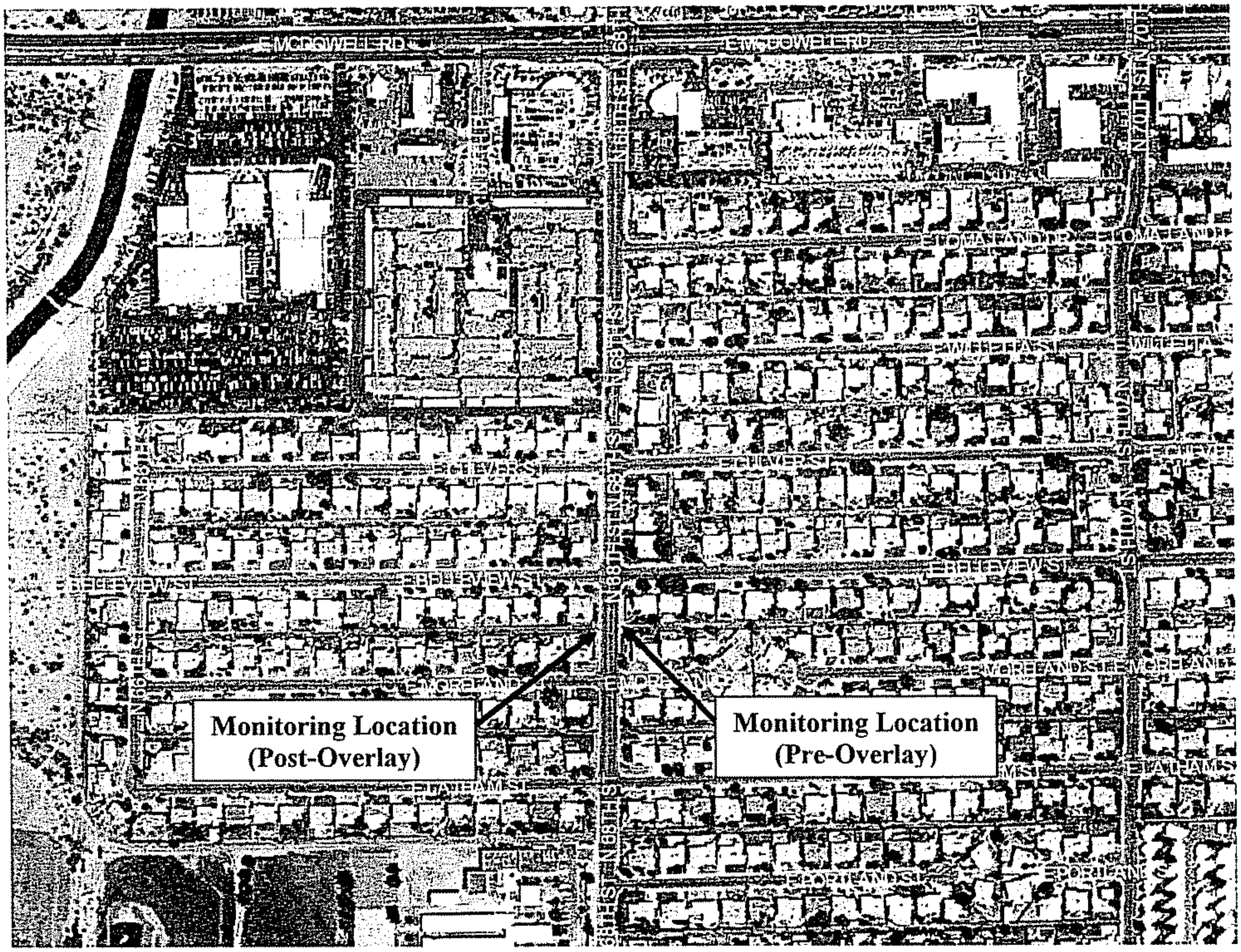
APPENDIX A
SHEET 2 OF 5

90TH STREET SITE
MONITORING LOCATION



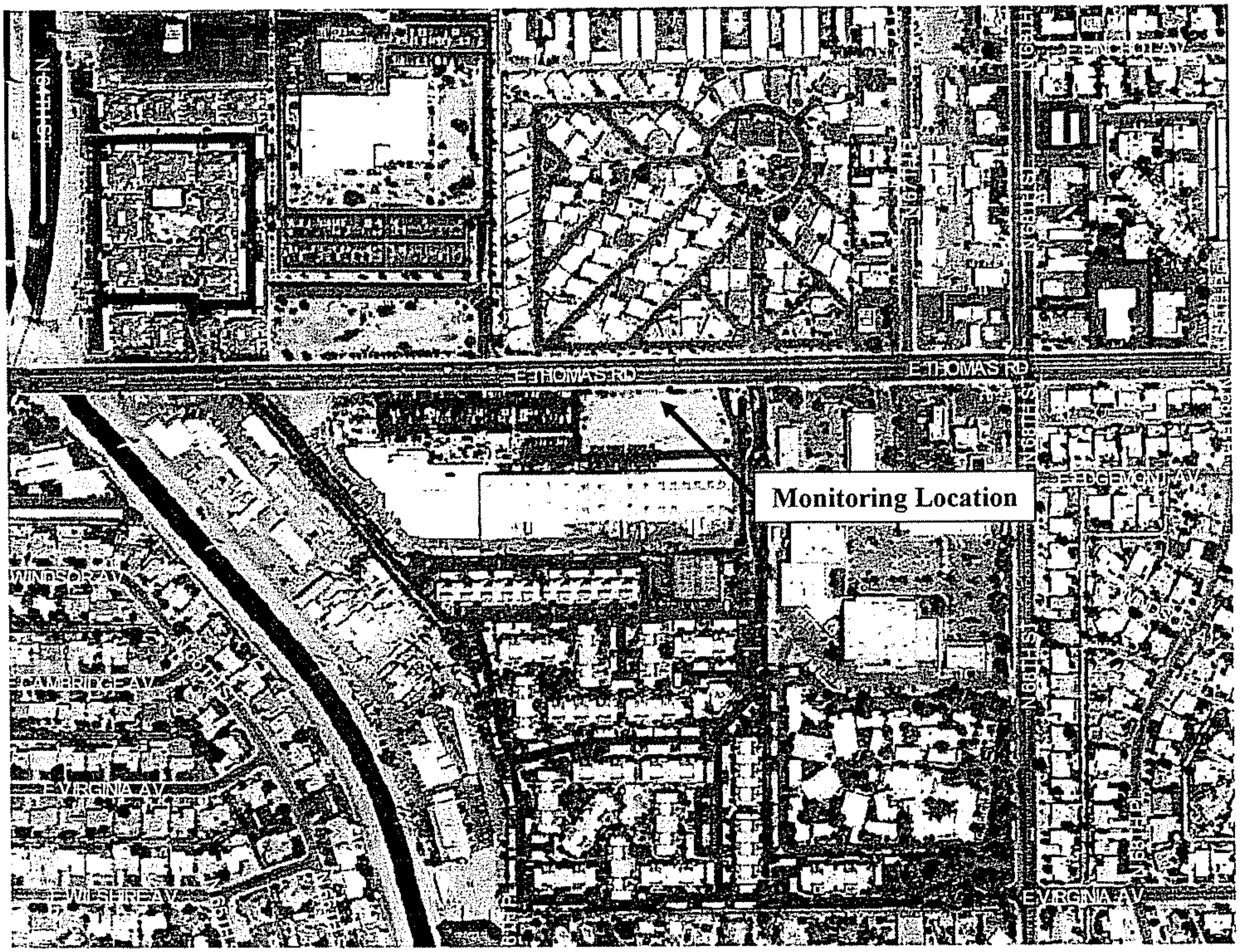
APPENDIX A
SHEET 3 OF 5

SHEA BOULEVARD SITE
MONITORING LOCATION



APPENDIX A
SHEET 4 OF 5

68TH STREET SITE
MONITORING LOCATION



APPENDIX A
SHEET 5 OF 5

THOMAS ROAD SITE
MONITORING LOCATION

APPENDIX B

TRAFFIC DATA

TRAFFIC DATA

Via Linda – 108th Street to 110th Street

Traffic Volume (1-Hour):

	Pre-Overlay		Post-Overlay	
	WB	*EB*	*WB*	*EB*
Automobiles	531	266	370	121
Medium Trucks	14	20	8	10
Heavy Trucks	0	0	0	0
Total Vehicles	545	286	378	131
Posted Speed (mph):	35	35	35	35

90th Street – Cactus Road to Sweetwater Avenue

Traffic Volume (1-Hour):

	Pre-Overlay		Post-Overlay	
	NB	*SB*	*NB*	*SB*
Automobiles	103	227	126	214
Medium Trucks	4	4	13	7
Heavy Trucks	2	0	0	0
Total Vehicles	109	231	139	221
Posted Speed (mph):	30	30	30	30

Shea Boulevard – Hayden Road to 84th Street

Traffic Volume (1-Hour):

	Pre-Overlay		Post-Overlay	
	WB	*EB*	*WB*	*EB*
Automobiles	1329	1129	1320	1224
Medium Trucks	42	64	42	62
Heavy Trucks	25	24	13	15
Total Vehicles	1396	1217	1375	1301
Posted Speed (mph):	45	45	45	45

68th Street – McDowell Road to Continental Drive

Traffic Volume (1-Hour):

	Pre-Overlay		Post-Overlay	
	NB	*SB*	*NB*	*SB*
Automobiles	443	229	301	302
Medium Trucks	14	11	9	12
Heavy Trucks	0	0	0	0
Totals	457	240	310	314
Posted Speed (mph):	35	35	35	35

Thomas Road – 64th Street to 68th Street

Traffic Volume (1-Hour):

	Pre-Overlay		Post-Overlay	
	WB	*EB*	*WB*	*EB*
Automobiles	813	781	1059	1174
Medium Trucks	24	36	32	34
Heavy Trucks	7	6	3	5
Totals	844	823	1094	1213
Posted Speed (mph):	40	40	40	40

APPENDIX C

CALCULATION SHEETS

Scottsdale - Overlay Study

Roadway Insertion Loss Noise Measurements

SITE NAME: Via Linda Site

"Before" Noise Level	Leq(1)	64 7
"After" Noise Level	Leq(2)	59 0

		EB		WB		Total		35 mph Equiv.		V_E
BEFORE	Cars	266	+	531	=	797	x	1	=	797
(Measurement 1)	MT	20	+	14	=	34	x	9 4	=	319 6
	HT	0	+	0	=	0	x	30 9	=	0
								Total $V_E(1)$	=	1117

		EB		WB		Total		35 mph Equiv.		V_E
AFTER	Cars	121	+	370	=	491	x	1	=	491
(Measurement 2)	MT	10	+	8	=	18	x	9 4	=	169.2
	HT	0	+	0	=	0	x	30 9	=	0
								Total $V_E(2)$	=	660

CORRECTION

Formulas:

$c = 10\mathrm{Log}_{10}[V_E(1)/V_E(2)]$ Leq(2N) = Leq (2) + c

c = 2.3 Leq(2N) = 61 3

COMPARISON

Before [Leq(1)] =	64 7
After [Leq(2N)] =	61.3
Difference =	3 4

"After" Noise Level at Via Linda Site is 3 4 decibels lower than "Before" Noise Level.

Prepared: 9/20/2004

Prepared By:
Higgins and Associates

Scottsdale - Overlay Study

Roadway Insertion Loss Noise Measurements

Site Name: 90th Street Site

"Before" Noise Level	Leq(1)	65 4
"After" Noise Level	Leq(2)	60 8

		NB		SB		Total		30 mph Equiv.		V_E
BEFORE	Cars	103	+	227	=	330	x	1	=	330
(Measurement 1)	MT	4	+	4	=	8	x	11 4	=	91 2
	HT	2	+	0	=	2	x	40 0	=	80
								Total $V_E(1)$	=	501

		NB		SB		Total		30 mph Equiv.		V_E
AFTER	Cars	126	+	214	=	340	x	1	=	340
(Measurement 2)	MT	13	+	7	=	20	x	11 4	=	228
	HT	0	+	0	=	0	x	40 0	=	0
								Total $V_E(2)$	=	568

CORRECTION

Formulas:

$c = 10\mathrm{Log}_{10}[V_E(1)/V_E(2)]$ Leq(2N) = Leq (2) + c

c = -0 5 Leq(2N) = 60 3

COMPARISON

Before [Leq(1)] = 65 4
After [Leq(2N)] = 60.3

Difference = 5 1

"After" Noise Level at 90th Street Site is 5 1 decibels lower than "Before" Noise Level

Prepared 9/20/2004

Prepared By:
Higgins and Associates

Scottsdale - Overlay Study

Roadway Insertion Loss Noise Measurements

Site Name: Shea Boulevard Site

"Before" Noise Level Leq(1) 68.3
"After" Noise Level Leq(2) 65 2

		EB		WB		Total		45 mph Equiv.		V_E
BEFORE	Cars	1129	+	1329	=	2458	x	1	=	2458
(Measurement 1)	MT	64	+	42	=	106	x	6.7	=	710.2
	HT	24	+	25	=	49	x	19 0	=	931
								Total V_E(1)	=	4099

		EB		WB		Total		45 mph Equiv.		V_E
AFTER	Cars	1224	+	1320	=	2544	x	1	=	2544
(Measurement 2)	MT	62	+	42	=	104	x	6 7	=	696.8
	HT	15	+	13	=	28	x	19 0	=	532
								Total V_E(2)	=	3773

CORRECTION

Formulas

$c = 10\text{Log}_{10}[V_E(1)/V_E(2)]$ Leq(2N) = Leq (2) + c

c = 0.4 Leq(2N) = 65 6

COMPARISON

Before [Leq(1)] = 68.3
After [Leq(2N)] = 65.6

Difference = 2.7

"After" Noise Level at Shea Boulevard Site is 2 7 decibels lower than "Before" Noise Level

Prepared: 9/20/2004

Prepared By:
Higgins and Associates

Scottsdale - Overlay Study

Roadway Insertion Loss Noise Measurements

Site Name: 68th Street Site

"Before" Noise Level	Leq(1)	67.5
"After" Noise Level	Leq(2)	64.5

		NB		SB		Total		35 mph Equiv.		V_E
BEFORE	Cars	443	+	229	=	672	x	1	=	672
(Measurement 1)	MT	14	+	11	=	25	x	9.4	=	235
	HT	0	+	0	=	0	x	30.9	=	0
								Total V_E(1)	=	907

		NB		SB		Total		35 mph Equiv.		V_E
AFTER	Cars	301	+	302	=	603	x	1	=	603
(Measurement 2)	MT	9	+	12	=	21	x	9.4	=	197.4
	HT	0	+	0	=	0	x	30.9	=	0
								Total V_E(2)	=	800

CORRECTION

Formulas:

$c = 10\text{Log}_{10}[V_E(1)/V_E(2)]$ Leq(2N) = Leq (2) + c

c = 0.5 Leq(2N) = 65.0

COMPARISON

Before [Leq(1)] = 67.5
After [Leq(2N)] = 65.0

Difference = 2.5

"After" Noise Level at 68th Street Site is 2.5 decibels lower than "Before" Noise Level

Prepared By:
Higgins and Associates

Prepared: 9/20/2004

Scottsdale - Overlay Study
Roadway Insertion Loss Noise Measurements

Site Name: Thomas Road Site

"Before" Noise Level Leq(1) 66 0
"After" Noise Level Leq(2) 64.2

		EB		WB		Total		40 mph Equiv.		V_E
BEFORE	Cars	781	+	813	=	1594	x	1	=	1594
(Measurement 1)	MT	36	+	24	=	60	x	7 8	=	468
	HT	6	+	7	=	13	x	24 1	=	313.3
								Total $V_E(1)$	=	2375

		EB		WB		Total		40 mph Equiv.		V_E
AFTER	Cars	1174	+	1059	=	2233	x	1	=	2233
(Measurement 2)	MT	34	+	32	=	66	x	7 8	=	514 8
	HT	5	+	3	=	8	x	24.1	=	192.8
								Total $V_E(2)$	=	2941

CORRECTION

Formulas

$c = 10\mathrm{Log}_{10}[V_E(1)/V_E(2)]$ Leq(2N) = Leq (2) + c

c = -0 9   Leq(2N) = 63 3

COMPARISON

Before [Leq(1)] = 66 0
After [Leq(2N)] = 63.3

Difference = 2 7

"After" Noise Level at Thomas Road Site is 2 7 decibels lower than "Before" Noise Level

Prepared By
Higgins and Associates

Prepared 9/20/2004

APPENDIX D

FIELD DATA SHEETS

APPENDIX 4

Report: “Development of Arizona’s Quiet Pavement Research Program”

Development of Arizona's Quiet Pavement Research Program

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ABSTRACT: *This paper provides information on continuing quiet pavement research work being done in the State of Arizona The historical development of the Arizona Department of Transportation's research activities leading to today's research program is outlined Different methods of measuring tire/pavement noise are discussed and compared Results of pavement noise testing for asphalt-rubber and Portland Cement Concrete pavements are presented Current and future planned projects are given*

KEY WORDS *Noise, pavement, acoustics, quiet*

1. Introduction

The Arizona Department of Transportation (ADOT) recently elected to place Asphalt Rubber Friction Course (ARFC) overlays over most of the Phoenix Metropolitan Area PCCP roadways to reduce traffic-generated noise This will be accomplished through a three-year, $34 million, program to construct ARFC overlays over the PCCP roadways starting in the fall 2003 ADOT expects to see a minimum 4 dBA reduction in the noise levels at the roadside as a result of the change from PCCP to ARFC surface type.

ADOT also became the first state to attain pilot status with the FHWA to allow pavement surface type as an alternative noise mitigation strategy. This status allows ADOT to take a 4 dBA credit for using an ARFC pavement surface. This credit could be used to eliminate or reduce wall heights The 4 dBA reduction is approximately equivalent to 8 ft of additional noise wall height To achieve the FHWA approval for a pilot program, ADOT agreed to a ten year, $1 million research effort targeted at validating the efficacy of the ARFC surfacing.

Prior to initiating the new ARFC overlay program, ADOT's PCCP had been constructed with uniformly spaced (3/4") transverse tining In 2001 ADOT changed to uniformly spaced (3/4") longitudinal tining Shortly after changing the PCCP tining specifications, ADOT elected to place ARFC overlays to reduce the traffic-generated noise even more. Currently, newly constructed PCCP that is intended to receive an ARFC overlay is constructed with astro-turf texturing while non-overlaid PCCP receives uniform longitudinal tining.

2. Objective

The objective of this paper is three fold: First, to describe the historical development of the Arizona Quiet Pavement Research Program; Second, to describe and contrast different methods of evaluating noise performance; Third, to present the current findings and future research efforts.

3. Historical Development

3.1 *PCCP Pavement Overlay Strategy*

Although the first use of asphalt rubber by ADOT was in 1964, the continued use of asphalt-rubber products began in 1968 [Sco 89] The development of an asphalt-rubber overlay system for PCCP began in 1973 with a two-layer system. The two-layer system was quickly replaced with a three-layer system in 1975 and the first non-experimental section was placed on I-17 in Phoenix in 1985. The three-layer system was eventually replaced by a one-inch thick ARFC. The first use of the ARFC strategy occurred on I-19 near Tucson, Arizona in 1988, when a one and one-half mile section of southbound I-19 was overlaid with a one inch ARFC. Portions of this overlay are still in service today.

The one-inch thick ARFC surfacing used in Arizona consists of a 3/8" minus, open-graded aggregate. Typical asphalt-rubber binder contents range between 9 to 9.4% by total mix weight. This overlay strategy was used for most of the PCCP overlay placements since 1988.

3.2 *Evolution of Noise Awareness and Pavement Noise Research*

Equally important to the technological advancement in pavement surfacing is the social awareness of noise pollution. As early as 1990, a study was conducted for International Surfacing to validate the noise reduction properties of the ARFC overlay placed on I-19 in 1988 [Wes 90]. The study reported that a 6.7 dBA reduction was obtained at a distance of 35 ft from the roadway. Although this overlay had been placed to restore ride quality, the public and the industry quickly noticed the attendant noise mitigation properties.

In the Phoenix area, subsequent ARFC overlay placements on I-17 provided similar public awareness to the benefits of a quiet pavement surface. As public sentiment towards quieter pavements increased, ADOT initiated its first formal research effort in 1995 when JHK and Associates conducted pavement noise research for the Department [Hen 96]. This study used both roadside and roadway-based measurement techniques.

The roadside measurement techniques consisted of conducting simultaneous noise measurements at locations where adjacent pavement surface types existed. This allowed for common traffic and environmental conditions. The locations of these sites are indicated in Figure 1. Figure 2 indicates the measurement positions for the microphones at location 1.

The roadway based testing consisted of positioning a microphone within a special windscreen and mounting it approximately 10 inches away from the rear tire of a 1995 Dodge Caravan. The intent of this effort was to develop a low cost system to allow for comparison of different pavement surface types. The set up is shown in Figure 3.

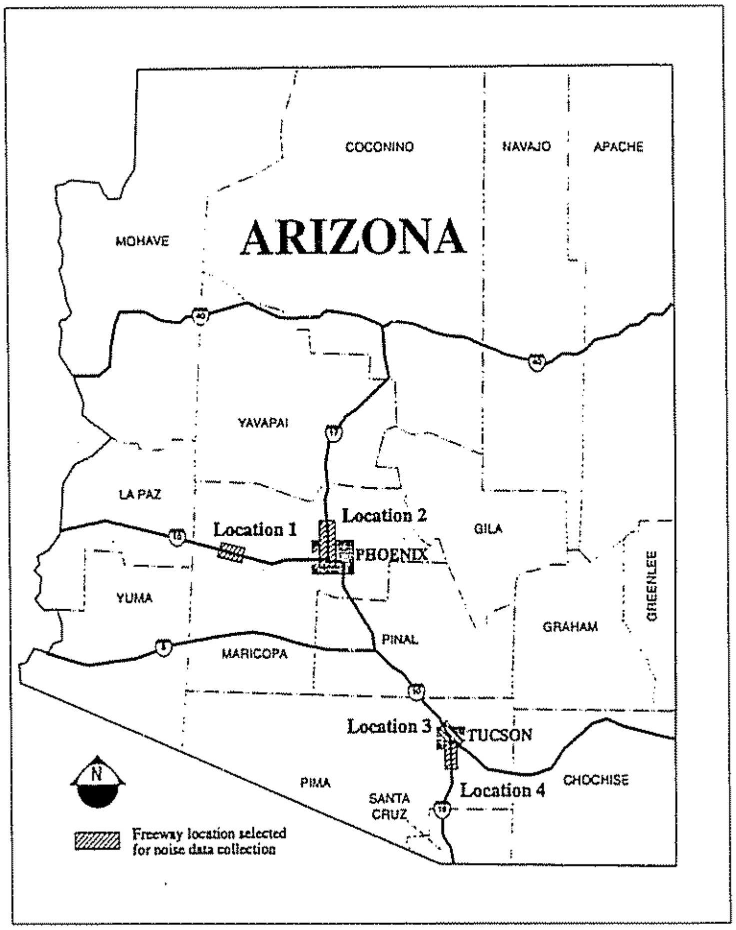
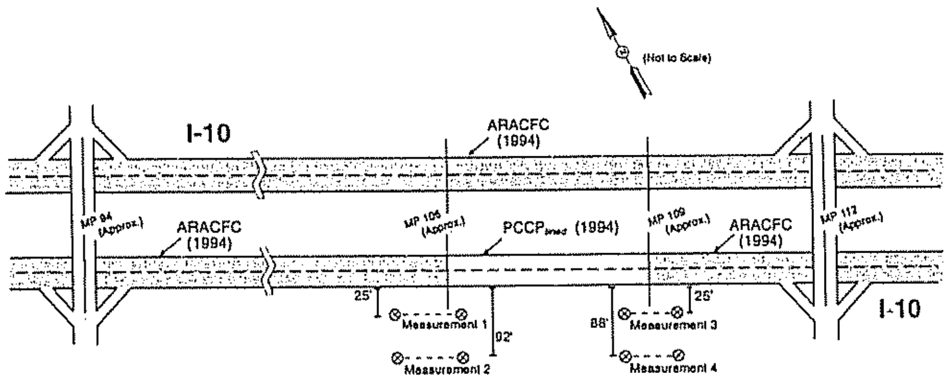


Figure 1: Location of 1995 Research Sites

Several of the study findings were:

— Roadside noise levels near a tined PCCP surface were 3.3 – 5.7 dBA greater than the levels measured near an adjoining ARFC surface. Based on four separate hourly measurements, the average difference between the two surfaces was 4.7 dBA.



Noise Monitoring Summary
(Location 1: March 13, 1995)

Simultaneous Measurements	Time	Leq dBA (1 hour) ARACFC	Leq dBA (1 hour) PCCP tined	Difference
Measurement 1	1:30 - 2:30 PM	71.8	77.5	5.7
Measurement 2	2:45 - 3:45 PM	63.9	68.5	4.6
Measurement 3	5:20 - 6:20 PM	72.9	78.2	5.3
Measurement 4	6:35 - 7:35 PM	66.5	69.8	3.3
			Average	4.7

LEGEND
- ⊗ Noise Monitoring Site
- ⊗- - -⊗ Simultaneous Noise Measurement

Figure 2: Microphone Schematic for Location 1 of 1995 Study

— No relationships were found regarding the different noise levels produced by ARFC segments of different ages using the roadway based measurements.

— Due to the high variability found for the ARFC surfaces, it was recommended that the most appropriate method for evaluating changes in noise characteristics is to periodically evaluate the individual surfaces as they age.

— Roadside measurements for a tined PCCP surface produced higher noise levels than an adjoining ARFC surface in the 800 – 3150 frequency region.

A subsequent evaluation using the roadway-based apparatus was conducted in 1998, by JHK & Associates, to update the 1995 study. The results of that effort indicated that the apparatus and vehicle configurations were not adequate to provide time stable measurements of the acoustic properties of the pavements surfaces.

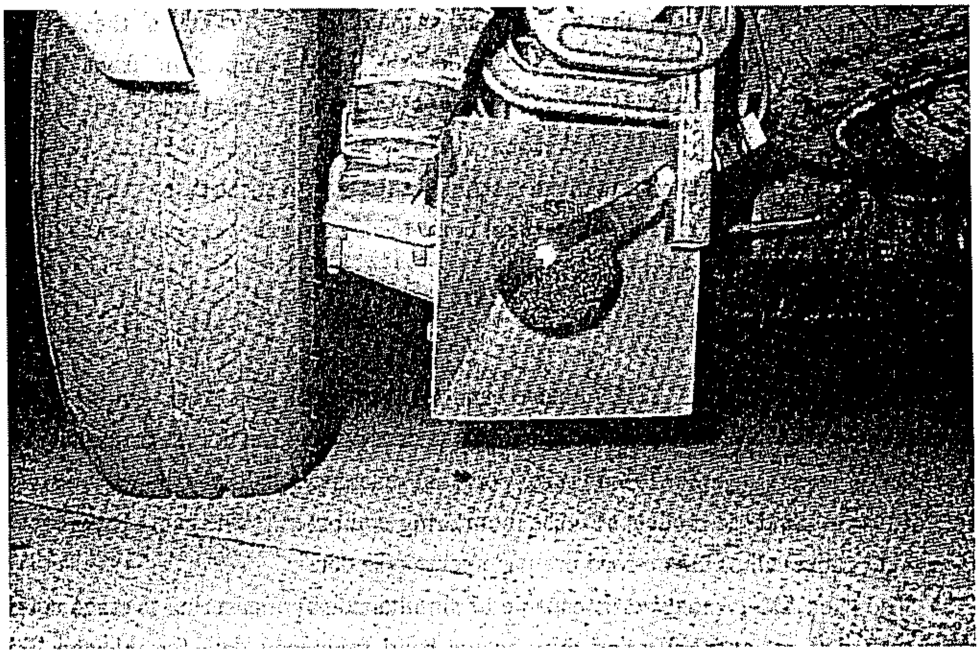


Figure 3: Microphone Attachment on 1995 Dodge Caravan

3.3 *Development of the ISO Close Proximity Trailer*

Early on it was recognized that the best way to evaluate changes in the acoustic properties of ARFC surfaces was to use a roadway-based measurement system that would exclude all other noise sources. The 1995 study attempt was a wishful, low budget attempt at this. However, the results confirmed that a dedicated vehicle system was necessary. In the spring of 2000, ADOT began actively seeking the development of such a system. The first attempt was to contact General Motors and determine how they conducted their noise research efforts. General Motors willingly provided a complete parts list to their noise trailer used for measuring tire/pavement interaction However, their trailer was based on the noise intensity measurement technology and ADOT did not understand the concept. That is, the noise intensity approach does not require an acoustic chamber to isolate the microphones. At the time, ADOT believed that this approach would not work on a trafficked roadway due to the lack of enclosure

In the spring of 2001 ADOT became aware of the ISO standards for the Close Proximity Trailer (e.g. CPX). At that time, it was decided to abandon the two previous trailer approaches, and construct an ISO compliant trailer. Completion of the ISO trailer occurred in the spring of 2002

Several months after completion of the CPX trailer by the National Center for Asphalt Technology (NCAT), ADOT became aware of a major research initiative by Caltrans that was using the noise intensity measurement technique. After meeting with Caltrans, it was agreed to pursue a collaborative research effort between ADOT and Caltrans. As part of that agreement, Caltrans provided the noise intensity fixtures and software to ADOT and NCAT

As part of the collaborative research effort it was agreed that the Goodyear Aqua Tread 3 tire, mounted on a 15 inch rim, would be considered the standard tire, and that a test speed of 60 mph would be used. Both of these decisions altered the ISO requirements. A cold inflation pressure of 30 PSI was also agreed upon.

During subsequent events, Caltrans provided consultant support to ADOT through Illingworth and Rodkin, Inc personnel, the integrators of the noise intensity approach [Don 03, Don 93]. This proved extremely valuable in further ADOT's noise research efforts. It ultimately resulted in Caltrans' test equipment measuring Arizona pavements and Arizona equipment measuring California pavements

3.4 *Evaluation of Changes in ARFC Noise Characteristics Over Time*

During the late 1990s and early 2000s, public sentiment for quiet pavements grew increasingly more vocal and assertive. Recognizing this, ADOT believed they needed to use pavement surface type as a noise mitigation strategy. However, the FHWA requirements did not allow pavement type as a mitigation strategy. The non-acceptance of pavement surface type, to a large extent, is based upon the belief that "quiet pavements" lose their noise attenuation characteristics after 3 to 5 years and hence are not a permanent solution

To counter the common belief regarding changes in ARFC characteristics, ADOT developed a test matrix based upon existing ARFC surfaced roadways. Since the application of the ARFC surfaces for noise properties would be confined primarily to the Phoenix area, only projects constructed in the desert climate were evaluated. The PMS system was used to develop a population of projects ranging between three and twelve years in age. The projects were then grouped by age distribution, and, in the summer of 2002, tested using both CPX and noise intensity measurement techniques.

The results of the CPX network evaluation are shown in Figure 4. The data indicate a weak relationship between noise level and pavement age. Extrapolating this relationship, the ARFC surfaces would have attained a value of approximately 93 dBA at construction and would increase approximately 5.5 dBA over ten years. More importantly, the pavements' acoustic life typically ranged between 94 and 98 dBA.

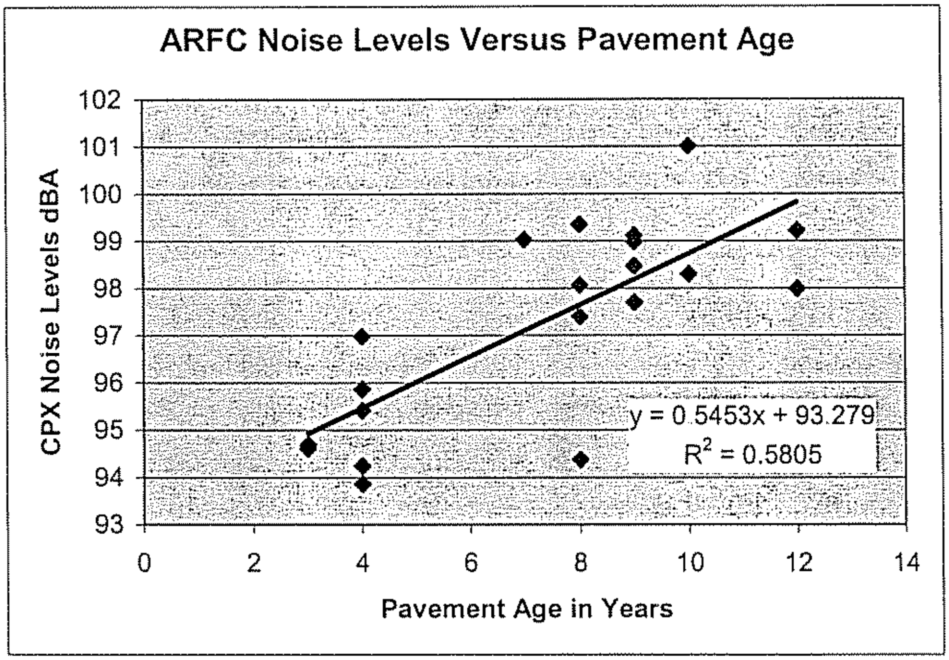


Figure 4: Network-Level Evaluation (CPX Method) of ARFC Noise Characteristics

Noise intensity measurements, obtained at the same time on the opposite wheel, suggested that there was no difference in noise characteristics as a function of age. However, ADOT considered the CPX values to be a conservative approach and ultimately used this data as the benchmark for ARFC performance assessment.

Several issues need to be considered when evaluating Figure 4. First, the ARFC surfaces studied were placed on flexible pavements, not PCCP. Second, the thickness used on these flexible pavements was 1/2 inch and not one inch as used on PCCP pavements. Third, the design life of the flexible pavements tested was ten years. So a large percentage of the data was obtained on pavements near their design life or that actually exceeded it.

Regressions against cracking, rutting, and roughness were performed. No relationship between cracking or rutting and noise could be established. Some trend between roughness and noise was noted, but the relationship was quite weak. (e.g. R2 = 0.25).

4. Evaluation of PCCP Surface Noise Characteristics

4.1 *Tining Test Sections*

During the spring of 2002, ADOT attempted to reduce PCCP pavement surface noise by altering the tining procedures used to texture. Previous research suggested that random transverse tining and longitudinal tining produced quieter pavement surfaces than uniformly spaced transverse tining [Way 98, Kue 00, Bur 01],

To evaluate the noise generation characteristics of different PCCP tining methods, ADOT constructed two types of tining on both the east bound and westbound roadways of an on-going SR 202 construction project in Mesa, Arizona.

The project, located between Gilbert and Higley road (approximately 4.5 miles), replaced the ADOT standard uniformly-spaced transverse tining with a uniformly-spaced longitudinal tining and a randomly-spaced transverse tining through a change order. The one-inch uniformly spaced longitudinal tining was constructed for a one-mile section at the west end of both the EB and WB roadways. The remainder of both roadways was textured using random-transverse tining in accordance with the Wisconsin DOT specifications. The PCCP had been recently constructed and had not been opened to traffic at the time noise testing was conducted.

On September 25, 2002 SR 202 was closed at the SR 87 (Country Club Drive) interchange to allow for controlled, roadside pass-by testing. This section of the 202 consisted of approximately four miles of the existing freeway, which had been opened to traffic approximately nine months earlier, and four miles of the newly constructed freeway (Gilbert to Higley) that had not been opened to traffic. Three test locations were established as shown in Figure 5. The controlled pass by testing was conducted at sites labeled RS1, RS2 and RS3.

The roadside pass-by test sites (ie. RS designations) were selected to provide the best acoustic conditions for the roadside testing

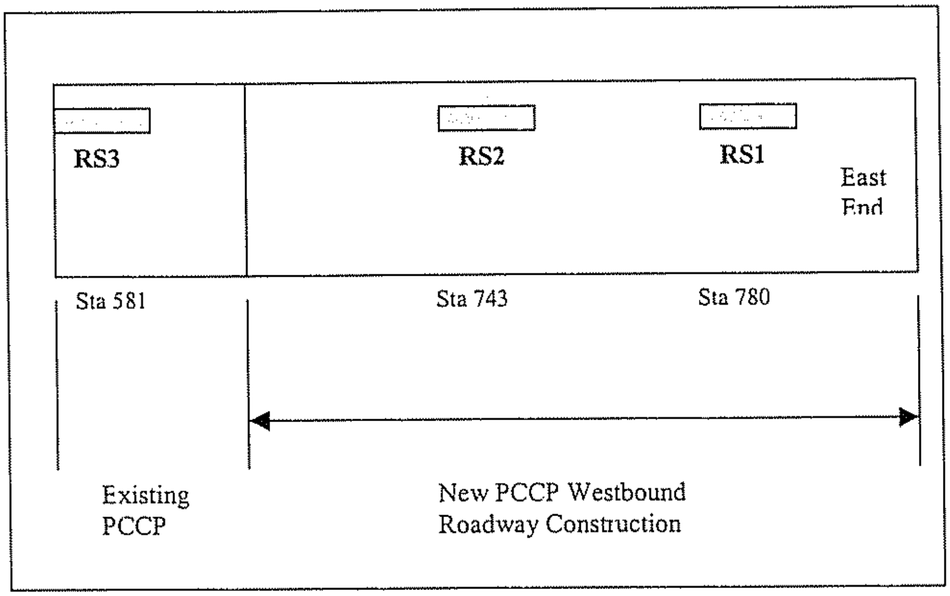


Figure 5: Pass-by Test Locations

For each of the roadside test locations, 32 vehicles representing three classes of vehicles were driven past each of the three points at approximately one-minute intervals for the passenger vehicles and two minute intervals for the medium and heavy trucks. Each of the passenger cars were driven by at 60 MPH and then again at 70 MPH.

Two types of vehicles, pickup trucks and sedans, represented the automobile category. Since a large portion of Arizona vehicles consists of SUVs or PUs, it was believed that a similar proportion should represent the autos in this category. Twenty sedans and 10 SUV/PU vehicles were used in the testing.

Two categories of trucks were included. The medium truck category was represented by only one vehicle, a F3500 Dodge. The heavy vehicle category was represented by two vehicles; an ADOT 10 wheeler and a commercial 16 wheeler that was half loaded with dirt. The ADOT ten-wheeler was operated empty.

In addition to the three categories previously described, a 1997 Subaru Outback owned by Illingworth and Rodkin, Inc. (I&R) was used to test the effect of different tires during the pass by testing. Although this vehicle was categorized as a passenger car, four passes were made. One pass at each of the two speeds for each of the following tires: Michelin Rainforce MX-4 and Goodyear Aqua Tread 3.

Measurements were obtained at 25 ft and 50 ft from the centerline of the travel lane at all three test locations. The US DOT Volpe Center collected the 50 ft measurements, as well as the environmental data and logged all the vehicle pass-by data. (I&R) personnel obtained measurements at the 25 ft locations and a 100 ft measurement at the site two location. Sites one and two were located on the new construction and site three was located on the existing freeway which had been opened to traffic approximately nine months earlier. ADOT provided vehicles and drivers.

In all, 64 passes were made by all the vehicles, including the I&R Subaru Test Vehicle. However, after eliminating those passes where noise contamination occurred such as aircraft and/or the driver did not reasonably conform to the speed requirements, there were only 41 good passes. There were 22 passenger car passes, 15 PU truck passes, three heavy vehicle passes, and one medium vehicle pass.

The 50 ft test results are shown in Figure 6 and 7. Figure 6 indicates the results from all vehicles and Figure 7 indicates the results from just the I & R test vehicle. The results, shown in Figure 6, indicate that the uniform longitudinal texture produced approximately a 5 dBA reduction over ADOT's standard texture which is a uniform one inch transverse texture. It also produced approximately an 8-9 dBA reduction over the Wisconsin random transverse texturing. All three tining methods resulted in approximately a 2 dBA increase between 60 and 70 MPH at the 50 ft measurement location.

Results for the 50 ft test locations for just the I&R test vehicle are shown in Figure 7. The results indicate the difference between the two tires used during testing.

Table 1 provides the results of the 50 ft testing when the passenger car data is broken into SUV versus Sedan. As evident from the data, the SUV vehicles produced small but consistently higher noise levels. As SUV type vehicles become increasingly more popular, their impact on noise should be taken into consideration. The composition of the pass-by vehicles was an attempt to simulate the actual fleet mix expected on this corridor.

Figure 8 represents a timeline of data obtained during testing at the random transverse tining test section. This figure shows all 32 runs per speed for each of the three-measurement distance (e.g. 25 ft, 50 ft, and 100ft). This is another way of presenting the data that is very useful. For example, the two high readings on the left-hand side of each of the speed zones indicates the heavy vehicles. The very low

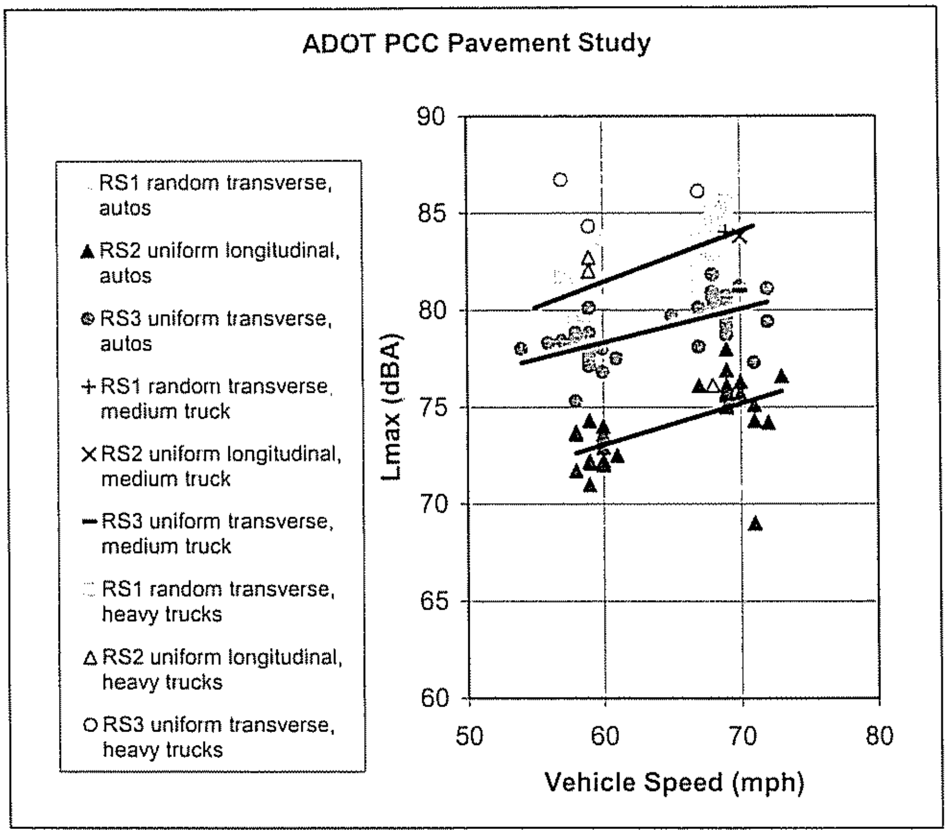


Figure 6: 50 ft Pass By Test Results

reading represents the driver that would only drive between the two traffic cones marking the lane at 35 mph no matter what the instructions were.

Figure 9 is a plot of the noise levels at each of the sites for each of the measurement distances. This also indicates the log (1/r**2) relationship that produces a similar trend to the measurements. A more complete discussion of this study is provided in technical paper by Donavan & Scofield [Don 03].

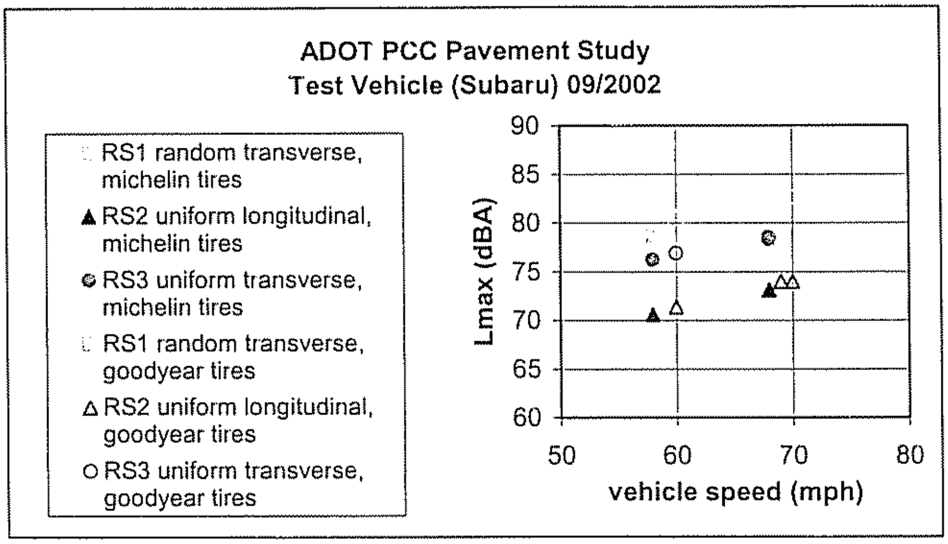


Figure 7 Test Results for 50 ft Location using I & R Test Vehicle

	Random Transverse	Change *	Longitudinal	Change *	Uniform Transverse	Change *
60 MPH						
Overall Avg	81 1		72 7		77 9	
SUV Avg	81.2	0 4	73 2	0 8	78.3	0 8
Passenger Car Avg	80 8		72 4		77.6	
70 MPH						
Overall Avg	83 6		75 3		80	
SUV Avg	83.9	0.6	76 1	1 6	80	0 2
Passenger Car Avg	83.3		74 5		79 9	

* Denotes percent increase of average SUV readings over average passenger car

TABLE 1: Comparison of 50 ft Roadside Readings For SR 202 Tining

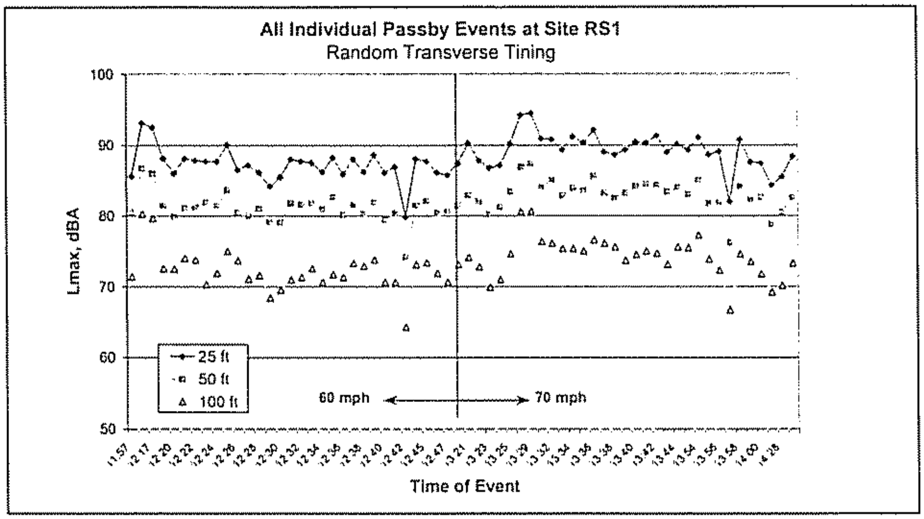


Figure 8: Time Line of All Test Passes as a Function of Speed and Test Distance for the Random Transverse Tined Section

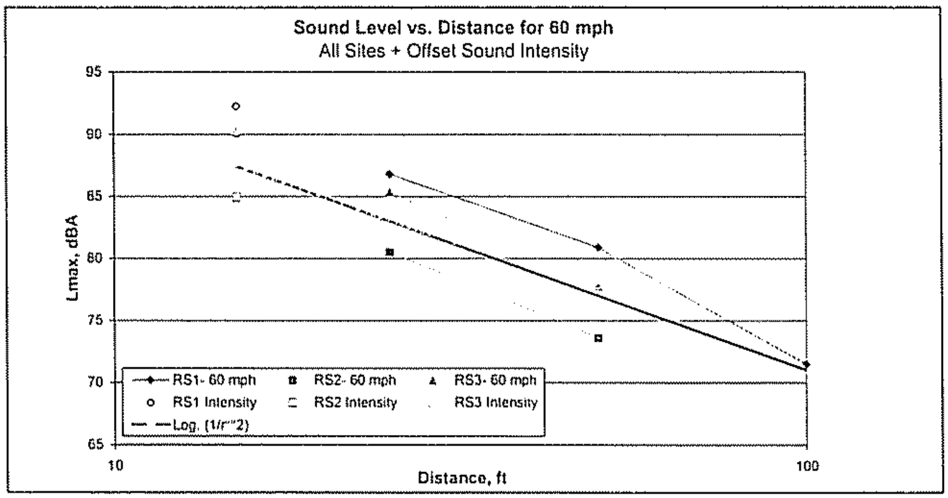


Figure 9: Sound Level Versus Distance for 60 MPH for All Sites

In regard to the three types of tining considered in this study, it was found that longitudinal tining produces lower noise levels than either of the transversely tined surfaces. Of the two transverse surfaces, it was found that the increase over the longitudinal tining was about 7 dB for the random and 5 dB for the uniform. The random transverse tining did smear the spectral peak associated with uniform tining, but created more overall energy. Inside the test vehicle, it was found that the random traverse tined surface produced levels higher than either of the two other surfaces between about 200 and 800 hertz apparently due to the details of the tine spacing.

In regard to evaluation methods, considerable scatter was found in the quasi-statistical passby results. Also the relative differences between pavement types changed with different passby microphone distances to the roadway, somewhat clouding the interpretation of the results. With averaging, the quasi-statistical passby data converged to that of the controlled test vehicle passbys and the on-board sound intensity. The results from the controlled test vehicle passbys were found to correspond very well to on-board sound intensity. To obtain conclusions regarding medium and heavy-duty track, considerably more passbys are required. More of these passbys should be included in a test plan, probably more on the order of the number of light vehicles. Even though this may not reflect the mix of the traffic expected on the freeway when open, more of these passbys are needed to obtain sufficient samples for averaging. Ideally, in evaluating tire/pavement noise, all the methods including time-average measurement of existing traffic would be employed as each have their strengths and weaknesses. However, for future work, when resources are limited or other constraints exist, priority should be placed on (in order): 1.) sound intensity or other near field measurements; 2.) wayside measurements of existing traffic; 3.) controlled vehicle passbys; and 4.) statistical or quasi-statistical passbys

4.2 *Diamond Grinding Test Sections*

On westbound SR 202 near I-10 in Phoenix, Arizona there is a section of PCCP that will not receive an ARFC overlay. This section, which is approximately 3000 ft in length, was constructed with uniformly spaced (3/4") longitudinal tining. The PCCP on one end of this area will receive an ARFC overlay in the fall of 2003. This situation provided a unique opportunity to evaluate a quiet concrete pavement surfacing at the same location as the ARFC quiet-pavement wearing course.

Due to the concern by the concrete industry that perfectly good PCCP was being overlaid with ARFC, they proposed to construct test sections using innovative grinding techniques that would provide similar noise reduction capabilities to ARFC overlays. They, in fact, constructed these test sections at their cost.

To accomplish this, the International Grooving and Grinding Association, the American Concrete Pavement Association, and the local cement industry funded construction of four test sections. The test sections consisted of diamond grinding a newly constructed section of PCCP. As part of the cooperative effort, ADOT agreed to provide acoustic testing of the surface during and after construction. The industry funded the work, and decided upon the techniques used to create the quiet pavement surface. ADOT is responsible for evaluating the sections for a minimum of three years.

Historically, the diamond grinding industry has developed techniques that were directed at providing very smooth pavements with good frictional properties. The industry had not focused on grinding techniques specifically directed at attaining a quiet pavement surface. These test sections were directed exclusively towards that lattergoal.

The four test sections, shown in Figure 10, are each 1000 ft in length resulting in a total test section length of 2000 ft in the west bound direction. The 2000 ft of test area is situated within the 3000 ft section of longitudinally tined PCCP that would not receive an ARFC surface.

The four grinding techniques are essentially based upon altering the spacing between grinding blades, and in the amount of head pressure and beam length used in constructing the sections. They can be summarized as follows:

— Profile grind using 0.110 blade spacing

— Profile grind using 0.110 blade spacing with jacks and a floating head (i.e. reduced down pressure)

— Profile grind using 0.120 blade spacing

— Profile grind using 0.120 blade spacing with jacks and a floating head (i.e. reduced down pressure)

The noise levels measured for these four surfaces treatments is also given in Figure 10 [Sco 03].

5. Evaluation of an ARFC Overlay Test Section Sponsored by the Public

In the fall of 2002, public sentiment towards quieter pavements attained a critical mass and as a result, ADOT constructed a one-mile long section of ARFC on SR 101 near 90 st in Scottsdale, Arizona. The purpose of this test section was to demonstrate the effectiveness of a quiet pavement approach.

CPX evaluations, conducted at 60 MPH, indicated that an 11 dBA reduction had occurred at the tire/pavement interface as a result of the ARFC overlay. In addition to the large reduction in overall noise, there was also a secondary and perhaps more dramatic change resulting from the ARFC surface that is discussed in the following paragraphs.

Figures 11 and 12 compare the differences between the 1/3 octave analysis and a narrow band analysis (e.g. 1/24 octave) conducted on the uniform-transverse tining prior to overlay placement. It should be noted that in Figure 12 there is a very distinct tonal spike evident at approximately 1500 hz. This spike is not evident in the 1/3 octave analysis (Figure 11) that is traditionally used for analysis in the transportation industry. The tonal spike that exists produces considerably more impact on human annoyance than its mathematical impact on the overall dBA for the spectrum. Human hearing finds tonal spikes such as evident in this spectrum particularly annoying. This type of tonal spike has been found to occur over a range of 1000 to 1500 hz on different segments of the PCCP network constructed with the same uniform-transverse tining requirements.

Comparing the pre-overlay spectrum shown in Figure 12 with the post-overlay spectrum in Figure 13, it is evident that the ARFC overlay provides more benefit than represented by just the overall average dBA level. As evident in Figure 13, the ARFC not only eliminates the tonal spikes, it also reduces the sound levels above approximately 800 hz and has a significant reduction between 1000 to 2000hz. There is also an appreciable reduction in the sound levels between 300 and 400 hz.

6. Development of the FHWA/Arizona Pilot Research Project

In April of 2003, the FHWA approved ADOT's request to use pavement surface type as a noise mitigation strategy. This decision was based, in part, upon the results of the ARFC network evaluation and the PCCP noise characteristics study and a large body of research provided by Caltran's. As previously described, ADOT and Caltrans' worked collaboratively on the pavement noise issue. As such, they collectively approached the FHWA regarding the pavement surface pilot program.

To obtain FHWA approval for a pilot program, ADOT agreed to a ten-year research program. The testing proposed to accomplish this research is shown in Appendix A. This plan is based upon three different site conditions, referred to as site type in Appendix A. CPX and noise intensity data will be collected at all three site types.

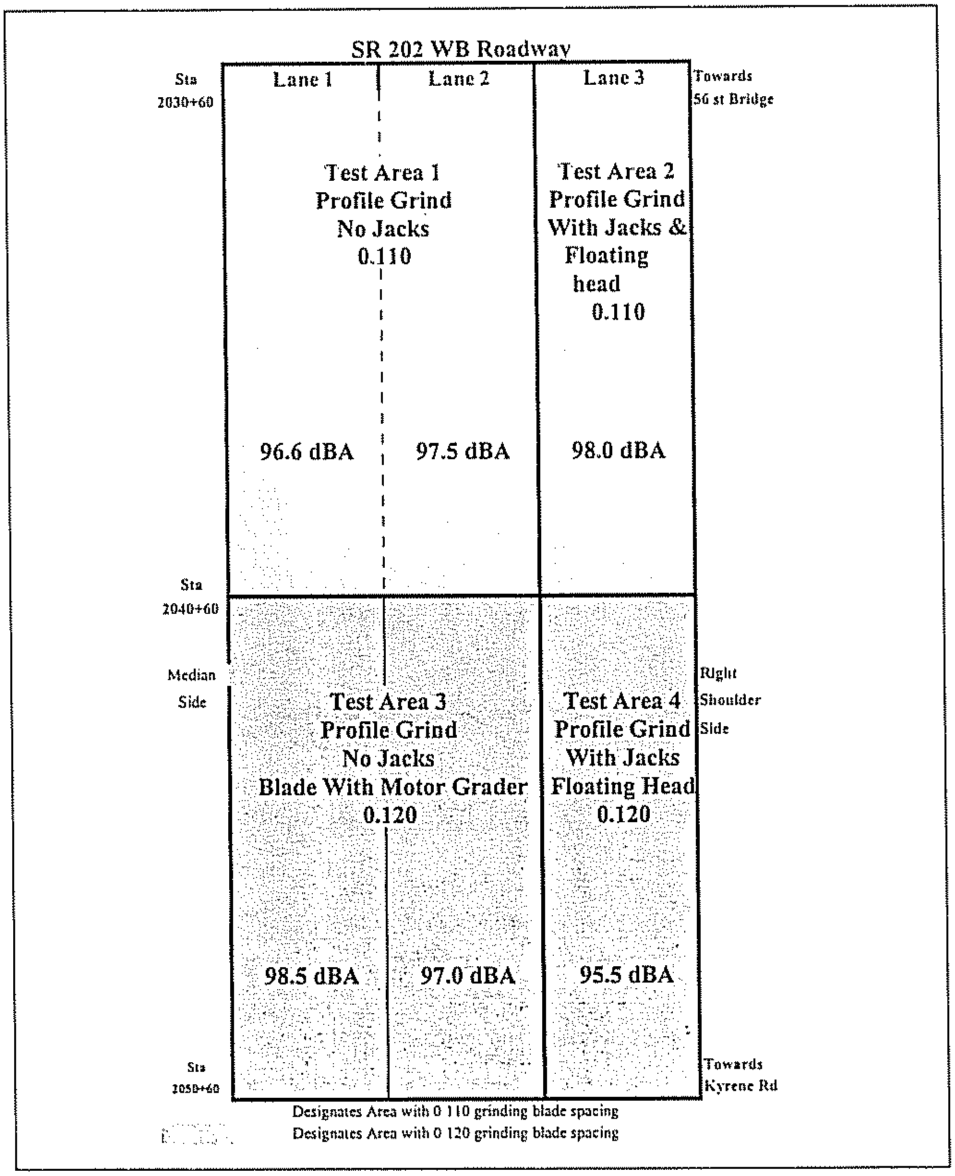


Figure 10: Diamond Grinding Test Section Layout

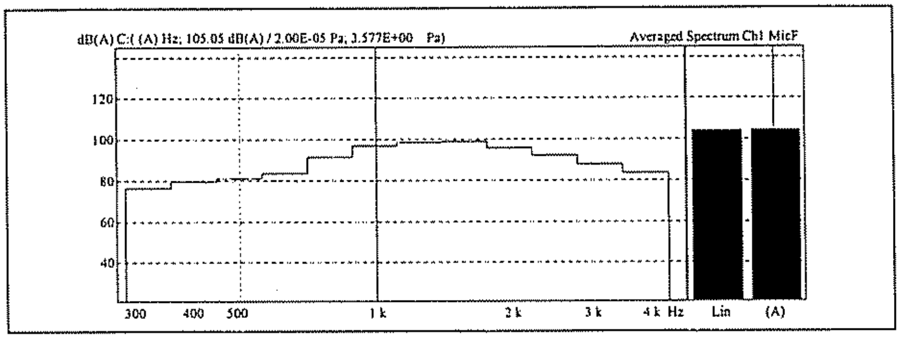


Figure 11: SR101 Pre-Overlay Spectrum Plot for 1/3 Octave Analysis for ADOT Uniform-Transverse Tining

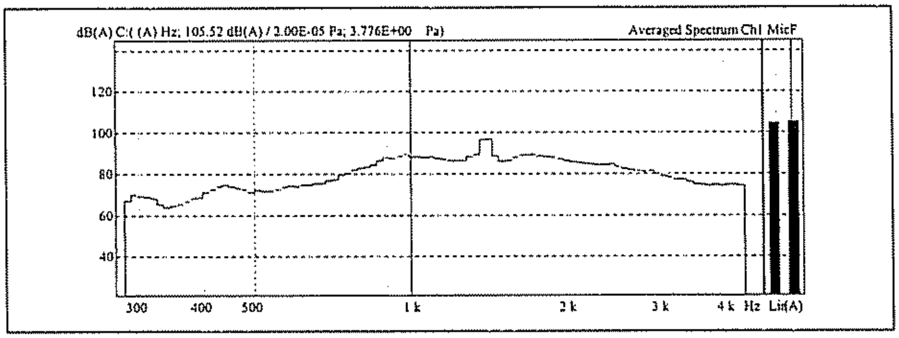


Figure 12: SR101 Pre-Overlay Spectrum Plot for 1/24 Octave Analysis for ADOT Uniform-Transverse Tining

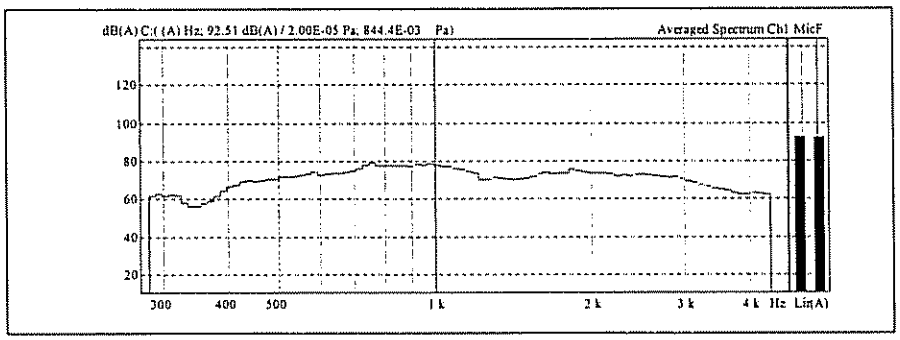


Figure 13: SR101 Post-Overlay Spectrum Plot for Narrow Band Analysis For ARFC

Site 1 designates ADOT's typical pavement management system data collection activity. That is, at each milepost, the specified pavement attribute is measured in the travel lane. This testing would occur for all milepost locations included within the construction of the quiet pavement overlays. Minimal environmental data would be collected at these sites.

Site 2 designates the sites that would typically be called conformance or compliance testing in ADOT's current program using wayside (far field), noise measurements. These sites are where ADOT would conduct before and after studies to evaluate how the residences are impacted.

Site 3 designates the research grade sites used primarily for wayside noise measurements. These are the locations that most closely resemble the "Ideal Conditions". These are the sites where relationships between near field and far field correlations will be attempted and are the highest quality field measurement sites. At Site 3 locations, acoustical, meteorological, traffic, and pavement data will be collected.

6.1 *An Overview of Arizona's Quiet Pavement Program*

Arizona's Quiet Pavement Research Program is a comprehensive research effort intended to produce quieter pavement surfaces, and to reduce traffic-generated noise in the communities. The program consists of three independent but inter-related research efforts. The three research efforts include the FHWA/ADOT Quiet Pavement Pilot program (e.g. composite pavement program), the flexible pavement program and the rigid pavement program.

ADOT is also conducting an SPR Research Project on "Determining the Atmospheric Effects on Highway Noise Propagation". This research will be conducted in support of the overall program, but is a separate activity.

6.2 *FHWA/ADOT Quiet Pavement Pilot Program*

This program is designed to evaluate the efficacy of using pavement surface type as a noise mitigation strategy. The research consists of evaluating the acoustic properties of ARFC surfaces, one inch in thickness, placed upon existing and newly constructed PCCP roadways. The research will evaluate the acoustic properties of the ARFC surfaces for the length of their original service life (which is expected to be a minimum of ten years). Both near field and far field acoustic measurements will be obtained. The research objectives are to:

— Validate the minimum 4 dBA reduction allowance for ARFC surfaces

— Quantify the acoustic properties of ARFC surfaces over time

— Determine the correlation between near field and far field acoustic measurements

— Evaluate selected pavement material properties for correlation to acoustic performance

— Validate the use of CPX and Noise Intensity measurement systems for evaluating acoustic properties of ARFC surfaces

— Determine the efficacy and benefits of using pavement surface type as a noise mitigation strategy

— Develop site/pavement specific REMELs for improved noise modeling

— Validate combining the CPX/NI measurement systems onto the same wheel of the trailer and conducting different tire measurements simultaneously

— Evaluate the seasonal or environmental aspects of the acoustic properties of the ARFC over time

—Determine the acoustic variability of an ARFC surface within a given construction project

7. Flexible Pavement Research Program

In addition to ARFCs used on PCCP, additional surface types and applications are being evaluated under the flexible pavement program Approximately 84 test sections have been placed since 1999 to evaluate six different surface types. These include: Permeable European Mixture, Stone Matrix Asphalt, ARFC, Neat-Asphalt Friction Course, Polymer-Modified Friction Course, and Terminal-Blend Asphalt Friction Course. In the near future it is anticipated that additional test sections employing a two-layer friction course, different thickness of ARFC, and additional terminal blend test sections will be constructed and included in this program.

The primary focus of this research effort is to evaluate the acoustic properties of different wearing course types placed over flexible pavements and to improve the performance of the ARFC strategy. Since construction of test sections on urban freeways is undesirable, improvements in wearing course design and construction will be evaluated in this program prior to implementation in the FHWA/ADOT Quiet Pavement Program (eg Composite Pavement Program).

This research is also focused on developing procedures for evaluating acoustic properties of pavement materials during the mix design stage. That is, in addition to designing for structure and durability, it is desirable to develop a methodology for evaluating mixtures for their acoustic properties prior to construction. This should allow for development of test procedures for conducting quality control testing during construction. The research objectives are to:

— Evaluate the acoustic properties of selected wearing course surfaces over time

— Develop correlations between near field and far field acoustic measurements

— Develop test procedures for evaluating mixtures in the mix design phase and for conducting construction quality control tests.

— Evaluate selected pavement material properties for correlation to acoustic performance

— Evaluate the seasonal or environmental aspects of the acoustic properties of the wearing courses over time

— Evaluate the network level acoustic performance of wearing course surfaces over time

— Validate combining the CPX/NI measurement systems onto the same wheel of the trailer and conducting different tire measurements simultaneously

8. Rigid Pavement Research Program

The rigid pavement research program is primarily concerned with establishing the acoustic properties of PCCP at the network level. This will allow characterization of these properties as a function of PCCP age prior to being overlaid with ARFC.

In addition to the network level evaluations, selected PCCP test sections involving grinding, tining, and transverse contraction joint design will be undertaken to support the overall quiet pavement program. The research objectives are to:

— Evaluate the acoustic properties of selected PCCP surfaces over time

— Determine the correlation between near field and far field acoustic measurements

— Validate the use of CPX and Noise Intensity measurement systems for evaluating acoustic properties of PCCP surfaces

— Develop site/pavement specific REMELS for improved noise modeling

— Evaluate the seasonal or environmental aspects of the acoustic properties of the PCCP over time

— Determine acoustic variability within a given construction project

9. Lessons Learned To Date

9.1 *Comparisons of Pavement Surface Type*

Although the ARFC overlay program has only recently commenced, several observations can be made relative to the performance of the evaluated surface types. As shown in Table 2, there is over a 10 dBA spread between the noisiest and the quietist surface types. This represents a noise level that is twice as loud.

The average ARFC value shown in Table 2 is lower than anticipated based upon the results of the network level analysis previously reported. This is presumably due to the fact that ARFC overlays are constructed one inch thick on PCCP instead of 1/2 inch thick as on flexible pavements.

Surface Texture Type	CPX Noise Level Measured at Tire (dBA)
Random Transverse (Wisconsin Spec)	104.9
ADOT Uniform Transverse tined (3/4")	102.5
ADOT Uniform Longitudinal Tined (3/4")	99.1
Whisper Grinding	95.5 (As-Constructed)
ARFC	91.8

Table 2: Comparisons of Pavement Noise Result [Sco 03]

9.2 Comparisons of Different Methods for Evaluating Noise Performance

The results from the controlled test vehicle passbys were found to correspond very well to on-board sound intensity during the PCCP texture testing. This fact suggests that further research is needed to verify weather noise intensity measurements, controlled passby, quasi-statistical, or statistical passby testing is the best method for managing a pavement network. The noise intensity and controlled passby methods over significant operational advantages

Both the CPX and noise intensity methods appear to characterize the pavements noise characteristics very well. However, the noise intensity measurement method offers significant operational advantages and allows a more rigorous theoretical approach ADOT's current plans are to continue simultaneous testing with both measurement systems for approximately one year of complete data collection and then migrate the program to noise intensity.

10.3 *Environmental Affects*

Perhaps the most significant finding to date may be the results obtained during the pre-overlay testing at the first Site 3 (e.g. research grade site) on SR 101 At this site, two hours of continuous data was obtained on each of two consecutive days On the first day, there was almost no wind. On the second day there were wind gusts of 4 to 6 mph

Microphone placement at this location consisted of two microphones at 50 ft (5 ft and 12 ft in height), one microphone at 100 ft at a height of 5 feet, and one microphone at 175 ft at a height of 5 ft.

As indicated in Figure 14, on the first day (no wind) the two 50 ft microphones all indicated similar results. The three offset test locations also produced similar results except for the distance effect. On the second day, however, (gusts of 4-6 MPH) it is evident that the two microphones at 50 ft no longer produce similar results and that the three microphone offset locations do not produce consistent relationships due to the existing environmental conditions

As a result of this finding, ADOT has restructured its research program to include a significant aspect on environmental testing. This testing will include 3D wind measurement during acoustic testing An attempt will be made during the first year of the Pilot Program to develop a relationship, if any, between measured acoustic properties and measured environmental properties.

Acknowledgements

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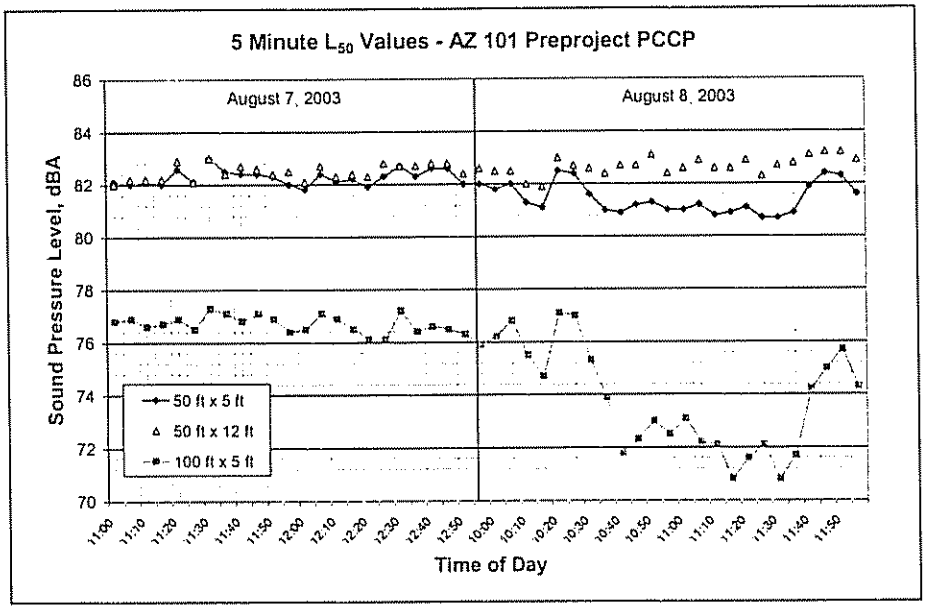

Figure 14: SR101 Site 3A Wayside Measurements

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Appendix A: ADOT/FHWA Pilot Program Test Plan

Test Type	Test Method	Test Duration	Test Frequency	Test Location	Before Test	After Test	Site ** Type	Evaluat Period
Near Field								
Close Proximity	ISO 11819-2*	7 second	Twice/Yr	MP	X	X	1,2,3	5+L Yrs
Noise Intensity	Caltrans Meth	7 second	Same as CPX	Same as CPX	X	X	1,2,3	"
Far Field (FF)	--See Note	2 Five Hr	Twice/Yr	Selected Residences	X***	X	2	3+L
	--See Note	2 Five Hr	Twice/Yr	50, 200, Distant	X***	X	3	5+L
Volume	--See Note -	SA FF	Twice/Yr	Rep. FF Testing		X	2, 3	SA FF
Speed	--See Note	SA FF	Twice/Yr	Rep. FF Testing		X	2, 3	SA FF
Surface Characteristics								
Outflow Meter		NA	Annually	Selected Location		X	3	5+L Yrs
CT Meter	ASTM E 2157	NA	Annually	Selected Location		X	3	5+L Yrs
Dynamic Fric Test	ASTM E 1911	NA	Annually	Selected Location		X	3	5+L Yrs
Runway Fric Test	ASTM E1859	NA	Annually	MP		X	1,3	5+L Yrs
Inertial Profiler	ASTM E950	NA	Annually	MP		X	1,3	5+L Yrs
Properties								
Complex Modulus ****		NA	3 Times	Site 3 Locations[5]	X	X	3[5]	0,3,8 yrs
Impedance Tube	ASTM E1050	NA	3 Times	Site 3 Locations[5]	X	X	3[5]	0,3,8 yrs
Air Flow	ASTM C522	NA	3 Times	Site 3 Locations[5]	X	X	3[5]	0,3,8 yrs
Void Content	ASTM D3203	NA	3 Times	Site 3 Locations[5]	X	X	3[5]	0,3,8 yrs
Asphalt Content	ASTM D2172	NA	3 Times	Site 3 Locations[5]	X	X	3[5]	0,3,8 yrs
Gradation	ASTM C 136	NA	3 Times	Site 3 Locations[5]	X	X	3[5]	0,3,8 yrs
Environmental								
Weather Station		SA FF	SA FF		X	X	2,3	SA FF

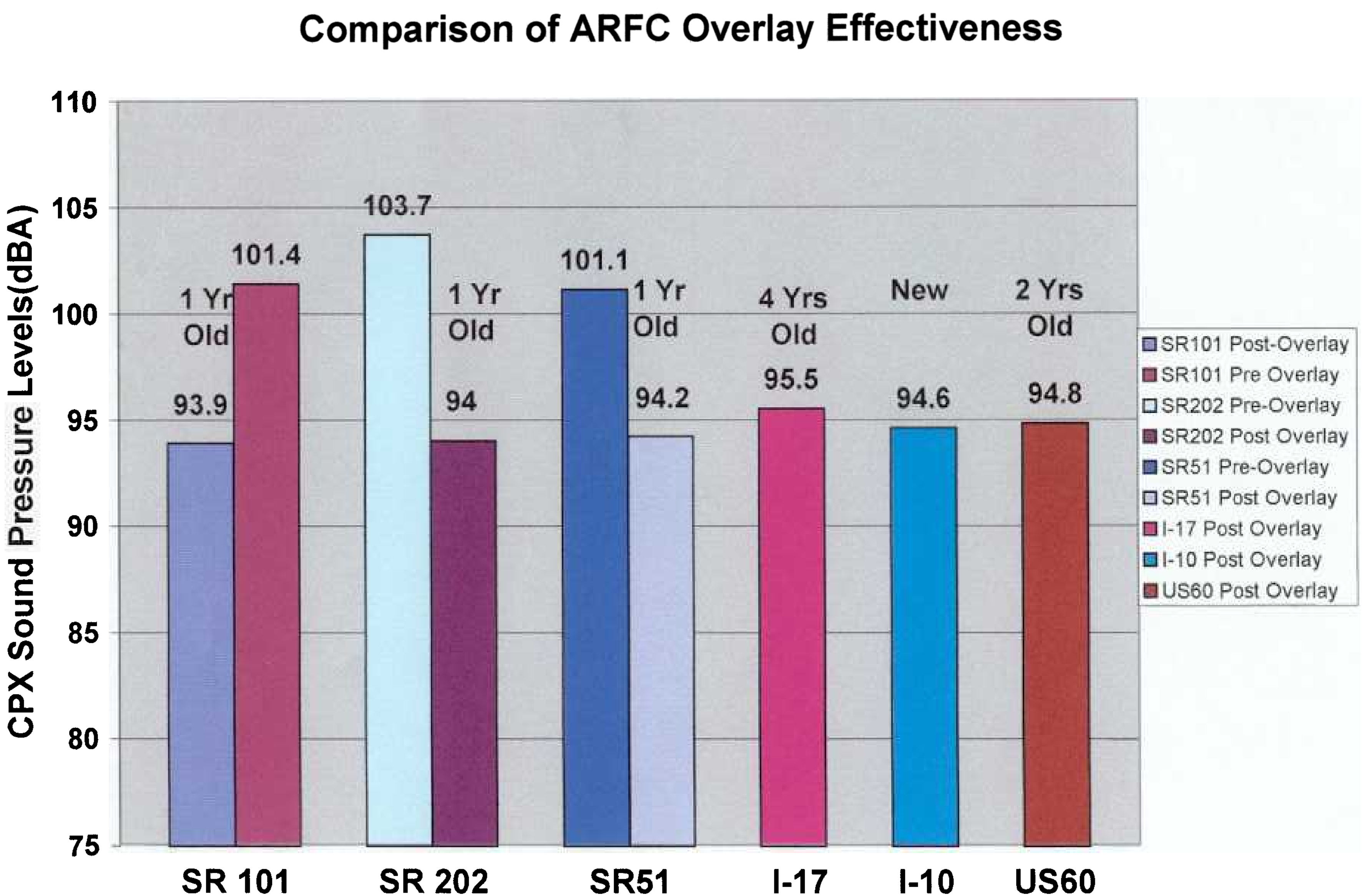
** Site Type Number 1= Annual Test at Milepost in Travel Lane Lane of Each Roadway Direction
Site Type Number 2= Site Specific Location and Test Plan Approval Required
Site Type Number 3= Research Grade Site (Establishing Relationships between near/farfield)
-- Described in Site 2 or 3 Workplans, Respectfully

*** Before Testing would be consists of Passby Testing Using Controlled Fleet (Three Vehicle Types)
**** Includes Determination of Dynamic Modulus and Damping Coefficient

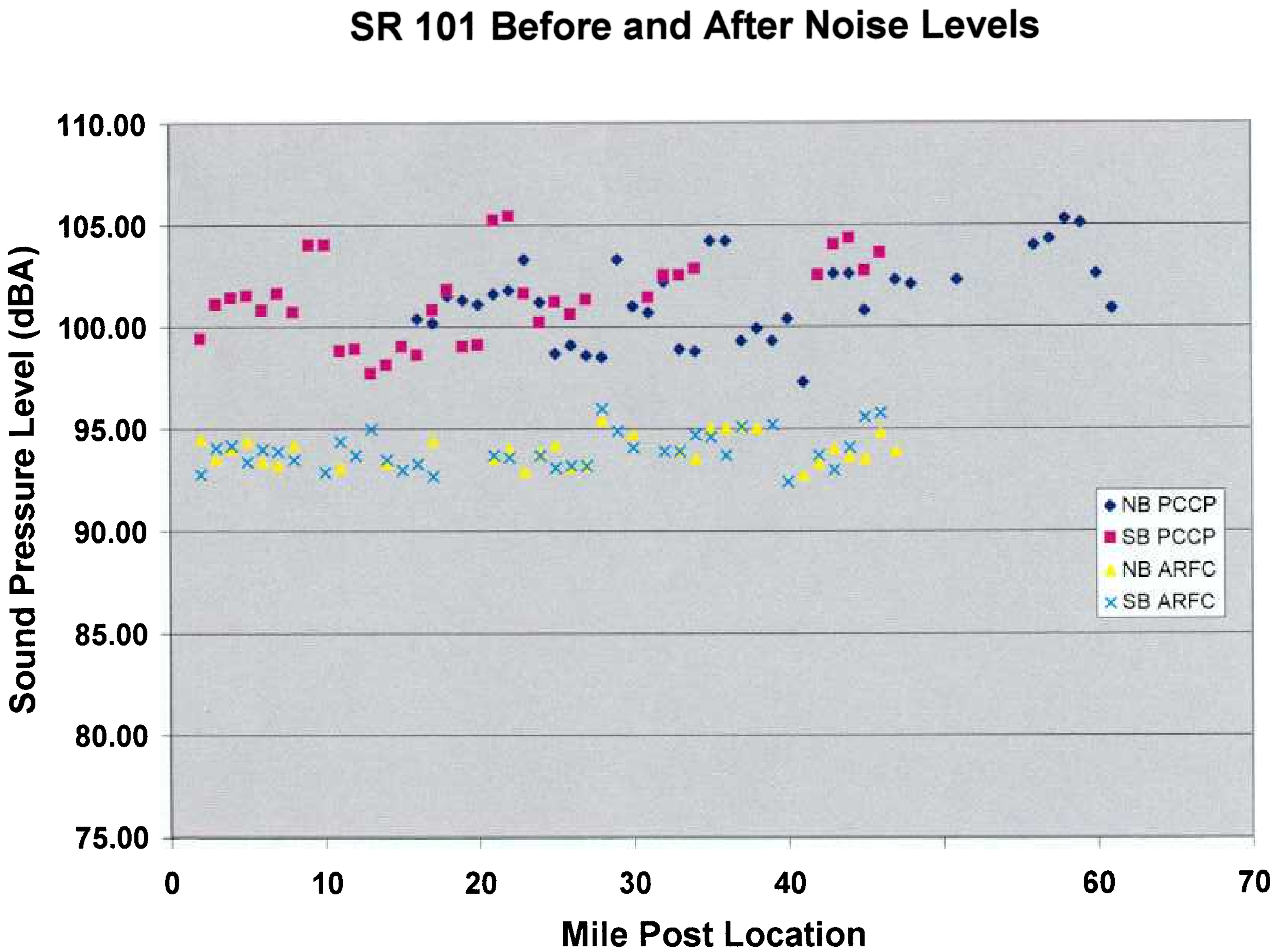
[5] At least one per construction project and at site three locations for:mix design stage,at 3 years,at 8 yrs
5 + L= Test Frequency will be modified after 5 yrs depending on results and continued for Service Life
3 + L= Test Frequency will be modified after 3 yrs depending on results
SA FF= Same As Far Field Testing

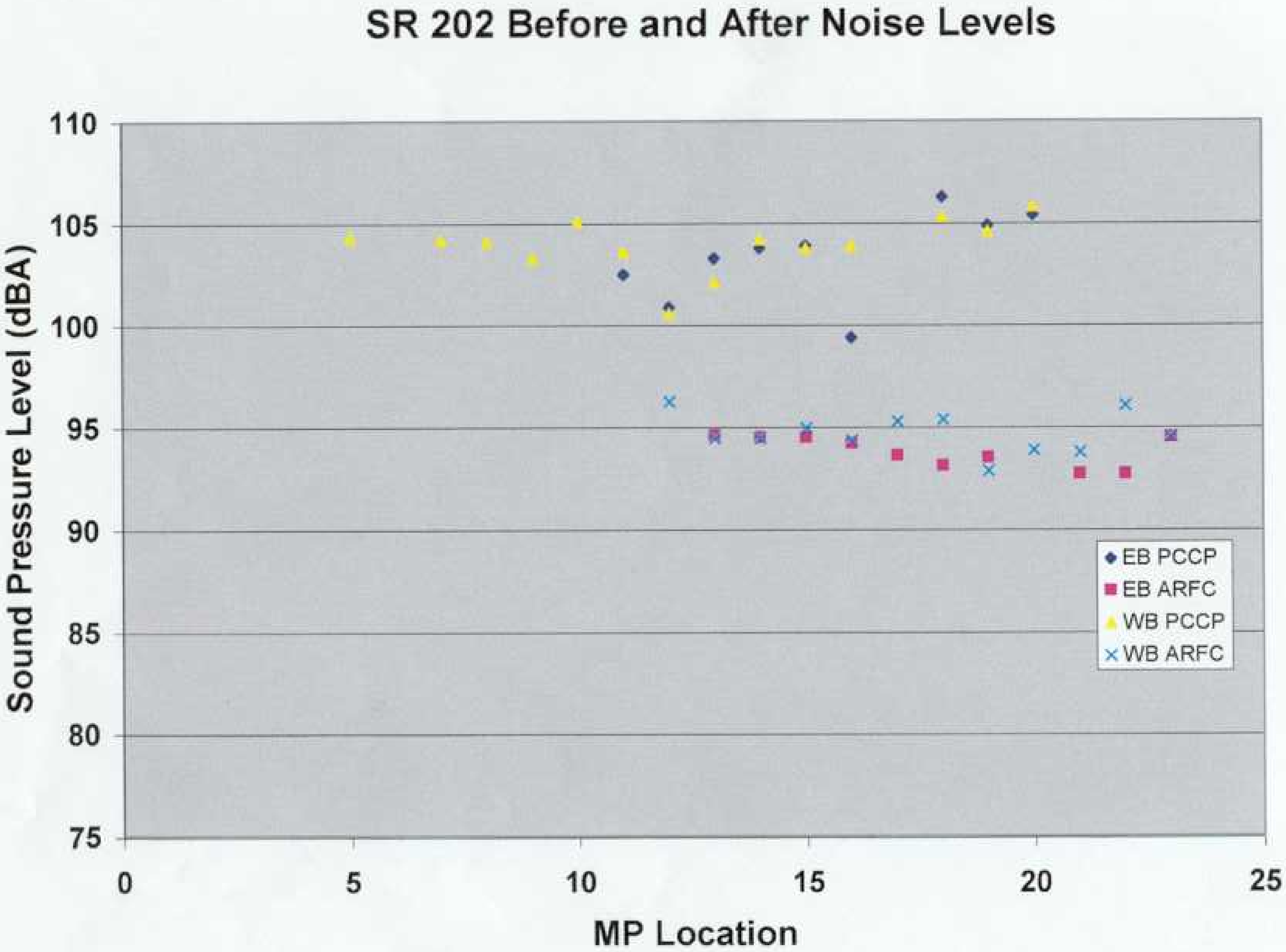
APPENDIX 5

Preliminary Site I Data

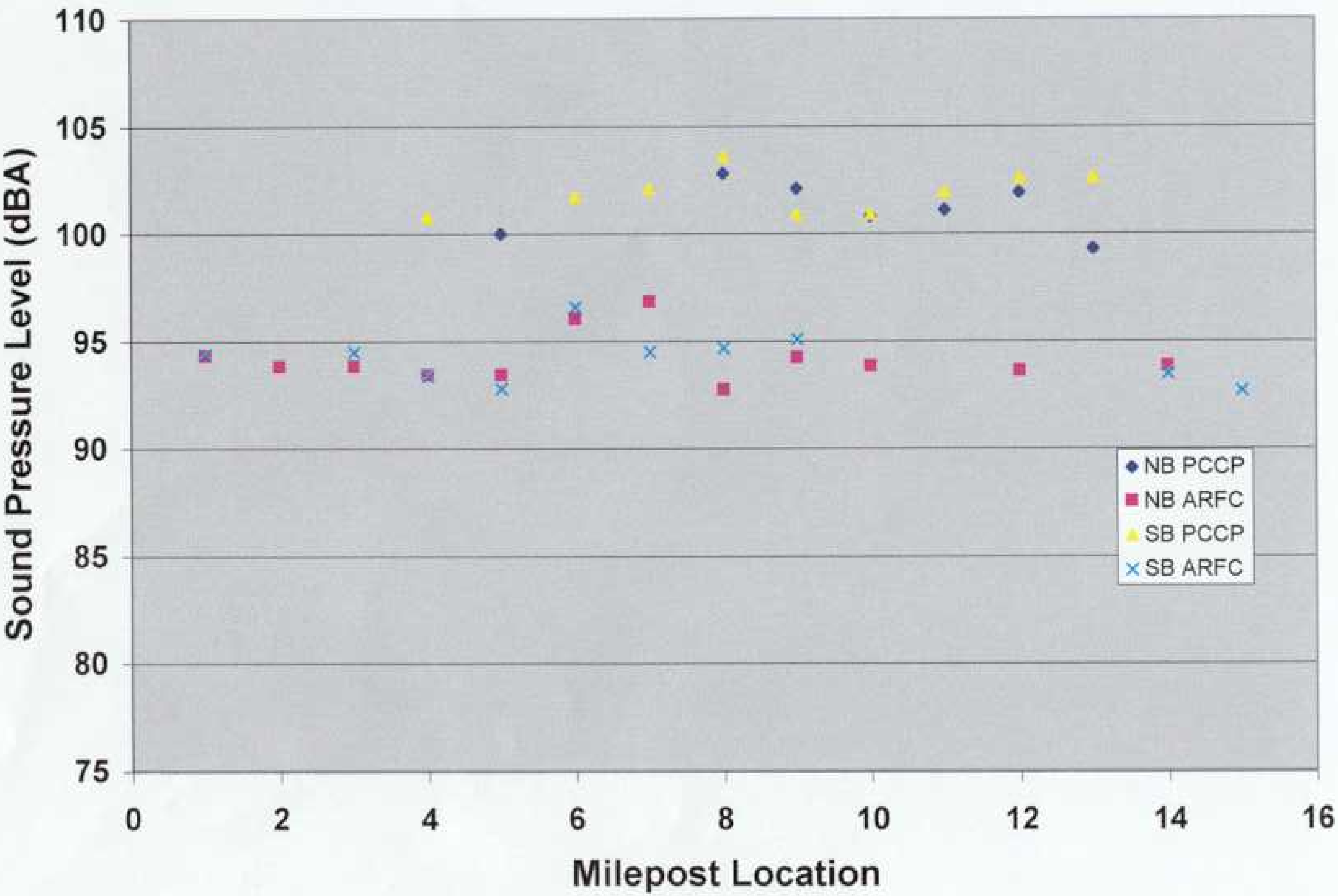


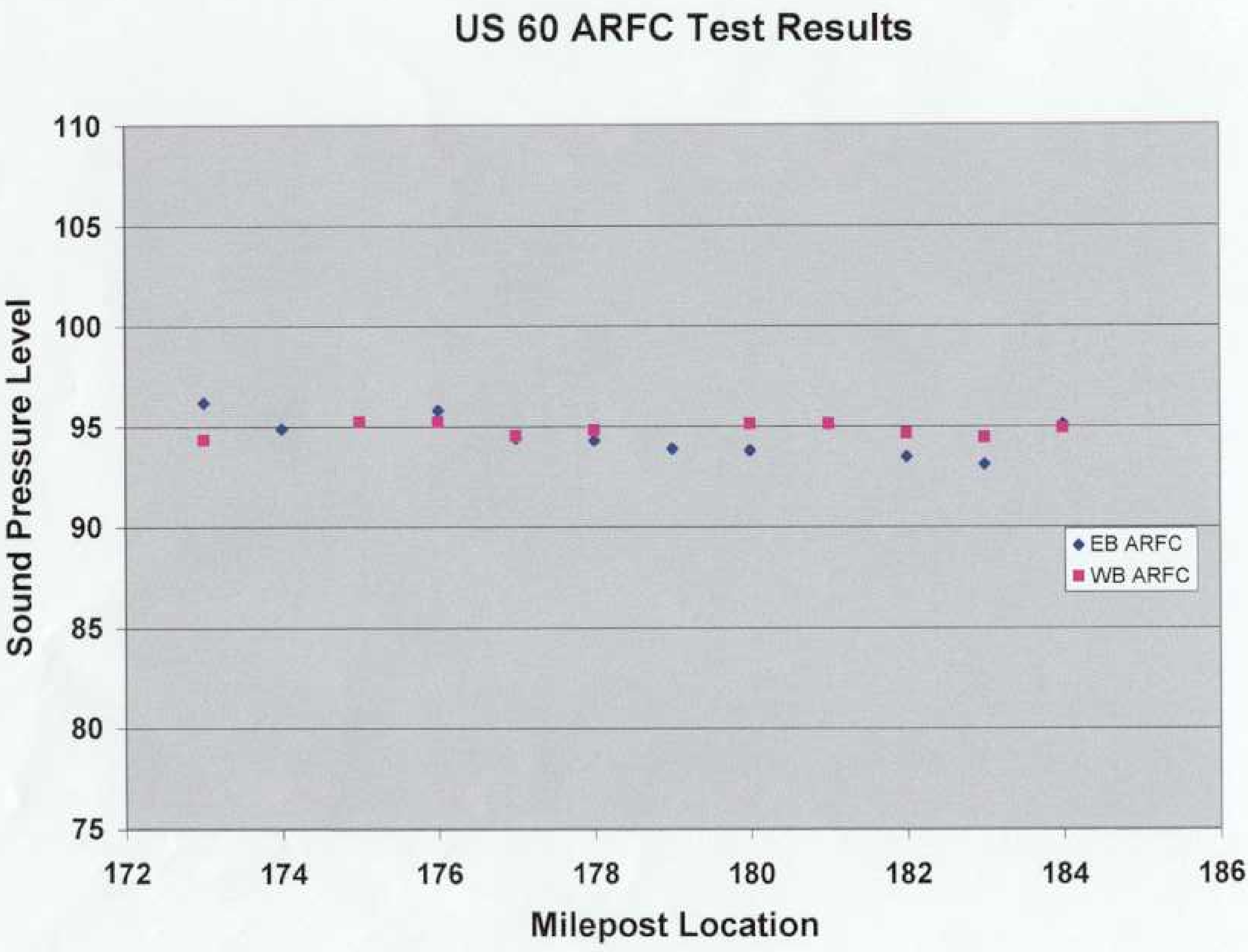
Comparison of ARFC Overlay Effectiveness
CPX Sound Pressure Levels(dBA)
110
105
100
95
90
85
80
75
101.4
1 Yr Old
93.9
103.7
1 Yr Old
94
101.1
1 Yr Old
94.2
4 Yrs Old
95.5
New
94.6
2 Yrs Old
94.8
SR 101
SR 202
SR51
I-17
I-10
US60
SR101 Post-Overlay
SR101 Pre Overlay
SR202 Pre-Overlay
SR202 Post Overlay
SR51 Pre-Overlay
SR51 Post Overlay
I-17 Post Overlay
I-10 Post Overlay
US60 Post Overlay


SR 101 Before and After Noise Levels
Sound Pressure Level (dBA)
110.00
105.00
100.00
95.00
90.00
85.00
80.00
75.00
0
10
20
30
40
60
70
Mile Post Location
NB PCCP
SB PCCP
NB ARFC
SB ARFC

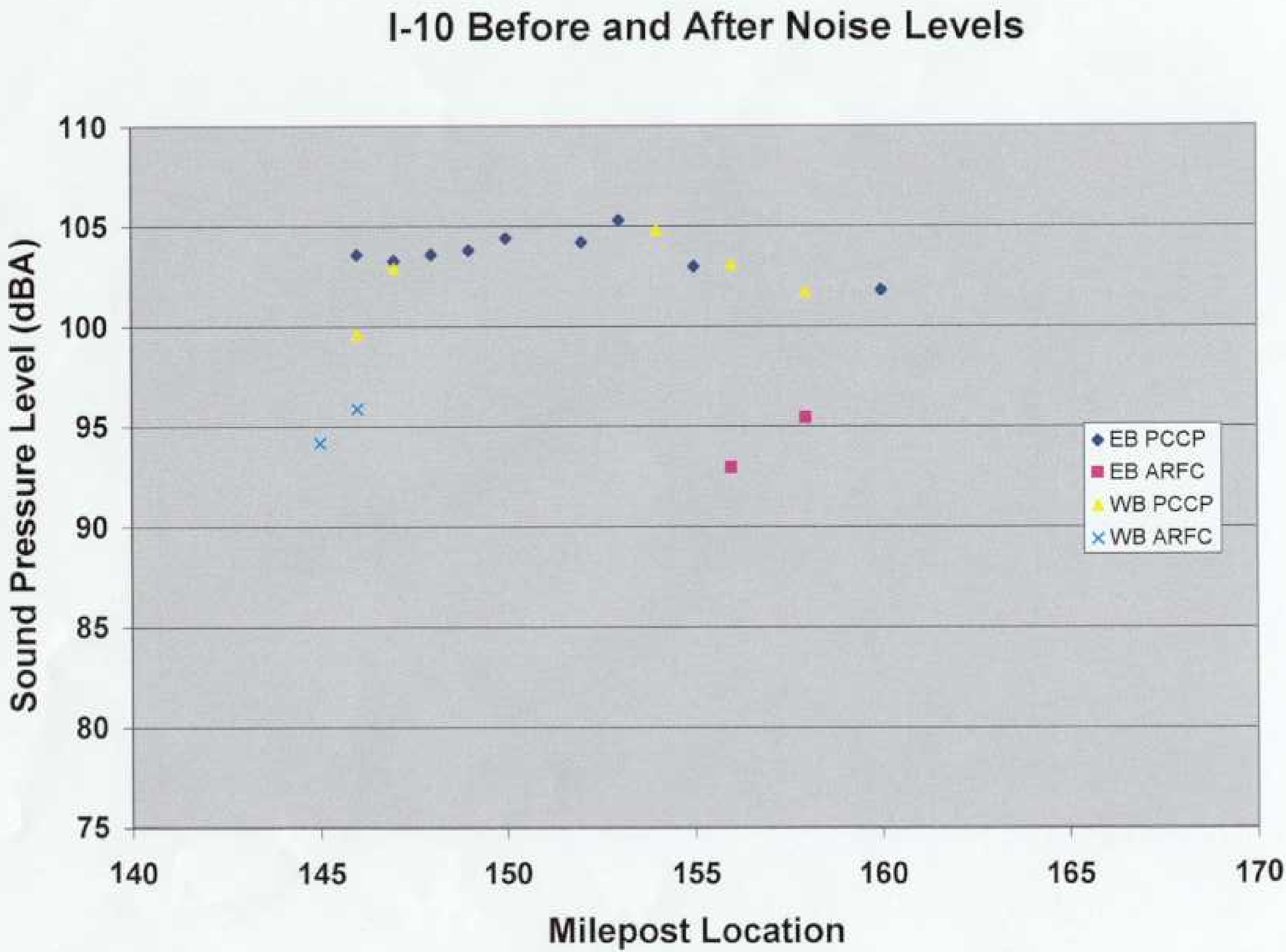

SR 202 Before and After Noise Levels
Sound Pressure Level (dBA)
110
105
100
95
90
85
80
75
0
5
10
15
20
25
MP Location
EB PCCP
EB ARFC
WB PCCP
WB ARFC

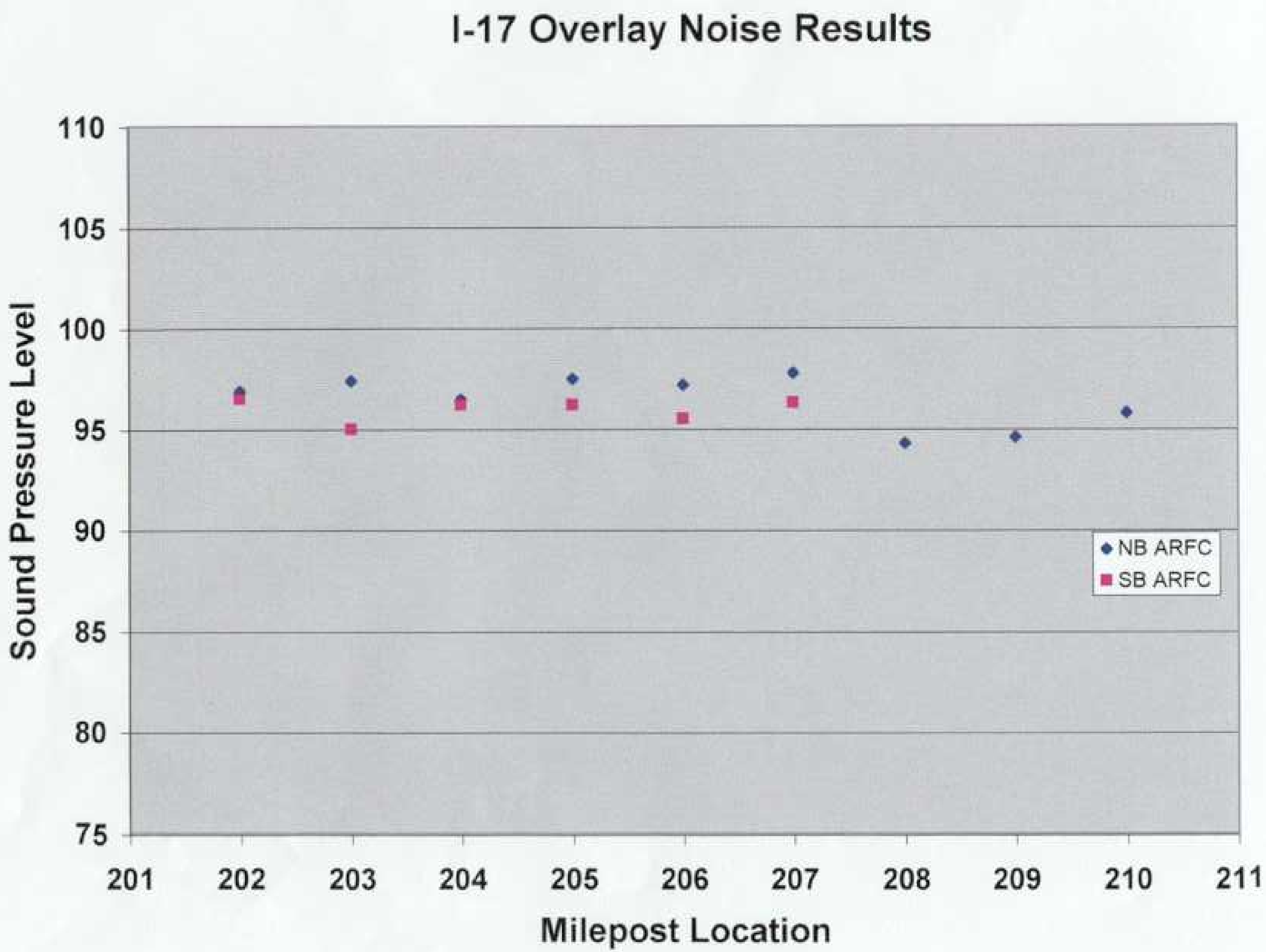
SR 51 Before and After Noise Results





US 60 ARFC Test Results
Sound Pressure Level
110
105
100
95
90
85
80
75
172
174
176
178
180
182
184
186
Milepost Location
EB ARFC
WB ARFC


I-10 Before and After Noise Levels
Sound Pressure Level (dBA)
110
105
100
95
90
85
80
75
140
145
150
155
160
165
170
Milepost Location
EB PCCP
EB ARFC
WB PCCP
WB ARFC


I-17 Overlay Noise Results
Sound Pressure Level
110
105
100
95
90
85
80
75
201
202
203
204
205
206
207
208
209
210
211
Milepost Location
NB ARFC
SB ARFC

APPENDIX 6

Preliminary Site II Data

ADOT Quiet Pavement Phase I

Pre and Post Overlay Readings

Pre-Overlay Data												Post-Overlay Data									Readings with Traffic Adjustment		
Site					Traffic Data				Noise Readings					Traffic Data				Noise Readings			Leq with Adjustment		
Route	Segment	Receiver	Date	Time	Avg. Speed	Autos	Med. Trucks	Hvy Trucks	Lmin	Lmax	Leq	Date	Time	Avg Speed	Autos	Med. Trucks	Hvy Trucks	Lmin	Lmax	Leq	Pre Leq	Post Leq	Reduction
L101	A	1	07/30/2003	11:45am - 12:45pm	67	6652 (94.23%)	241 (3.41%)	166 (2.35%)	62.7	81.5	74.6	11/06/2003	11:30am - 12:30pm	65	6944 (93.53%)	227 (3.05%)	253 (3.40%)	60.2	81	69.8	74.6	69.3	5.3
L101	A	2	07/30/2003	11:45am - 12:45pm	65	6652 (94.23%)	241 (3.41%)	166 (2.35%)	60.0	72.2	64.3	01/29/2004	10:18am - 11:18am	65	6322 (93.39%)	321 (4.74%)	126 (1.86%)	49.7	68.4	55.5	64.3	55.7	8.6
L101	A	3	07/30/2003	10:17am - 11:17am	65	5226 (92.92%)	302 (5.36%)	96 (1.70%)	59.0	72.4	64.6	11/06/2003	10:00am - 11:00am	65	6431 (93.37%)	207 (3.00%)	249 (3.61%)	52.1	69.5	59.7	64.6	58.5	6.1
L101	A	4	07/30/2003	10:15am - 11:15am	65	5226 (92.92%)	302 (5.36%)	96 (1.70%)	61.2	76.8	66.5	01/27/2004	10:13am - 11:13am	65	7125 (92.13%)	486 (6.28%)	122 (1.57%)	53.8	77.7	60.6	66.5	59.2	7.3
L101	A	5	08/05/2003	9:30am - 10:30am	65	6383 (93.44%)	215 (3.14%)	233 (3.41%)	50.3	69.9	55.6	01/28/2004	9:42am - 10:42am	65	7231 (92.91%)	399 (5.12%)	152 (1.95%)	47.7	59.7	52.5	55.6	52.2	3.4
L101	A	6	07/29/2003	11:00am - 12:00pm	65	6164 (93.60%)	313 (4.75%)	108 (1.64%)	52.6	70.1	59.3	01/28/2004	11:07am - 12:07pm	65	7368 (92.95%)	431 (5.43%)	127 (1.60%)	49.1	72.4	57	59.3	56.1	3.2
L101	A	7	08/05/2003	11:00am - 12:00pm	65	7086 (93.66%)	255 (3.37%)	224 (2.96%)	51.1	75.9	60.7	10/29/2003	11:02am - 12:02pm	65	6348 (92.80%)	298 (4.35%)	194 (2.83%)	47.5	76.7	58	60.7	58.4	2.3
L101	A	8	07/29/2003	11:05am - 12:05pm	65	6164 (93.60%)	313 (4.75%)	108 (1.64%)	56.7	78.6	64.9	10/29/2003	11:00am - 12:00pm	65	6348 (92.80%)	298 (4.35%)	194 (2.83%)	51.2	73.3	59.5	64.9	59.1	5.8
L101	A	9	07/29/2003	9:30am - 10:30am	65	6788 (93.17%)	349 (4.79%)	148 (2.03%)	63.3	84.0	73.1	10/29/2003	9:30am - 10:30am	65	6260 (92.15%)	312 (4.59%)	221 (3.25%)	59.5	83.3	69.6	73.1	69.6	3.5
L101	A	10	07/29/2003	9:30am - 10:30am	65	6788 (93.17%)	349 (4.79%)	148 (2.03%)	63.2	79.9	69.0	10/29/2003	9:33am - 10:33am	65	6260 (92.15%)	312 (4.59%)	221 (3.25%)	58.4	78.6	65.5	69	65.5	3.5
L101	A	11	07/29/2003	9:30am - 10:30am	65	9279 94.19%)	315 (3.19%)	257 (2.60%)	63.5	81.0	70.1	02/10/2004	10:27am - 11:27am	65	7545 (92.64%)	448 (5.50%)	151 (1.85%)	58.4	80.6	66.7	70.1	67.5	2.6
SR51	B	1	08/07/2003	4:00pm - 5:00pm	65	9747 (98.45%)	115 (1.16%)	38 (0.38%)	59.8	71.7	64.2	A											
SR51	B	2	08/07/2003	4:00pm - 5:00pm	65	9747 (98.45%)	115 (1.16%)	38 (0.38%)	60.7	76.9	66.3												
SR51	B	3	08/12/2003	4:00pm - 5:00pm	65	8274 (97.68%)	160 (1.88%)	36 (0.42%)	63.9	73.1	68.4												
SR51	B	4	08/13/2003	4:00pm - 5:00pm	65	5703 (98.41%)	75 (1.29%)	17 (0.29%)	62.6	76.7	67.4	10/28/2003	5:15pm - 6:15pm	65	9746 (98.66%)	115 (1.16%)	17 (0.17%)	54.1	69.3	59.9	67.4	57.6	9.8
SR51	B	5	08/13/2003	5:30pm - 6:30pm	65	5009 (99.22%)	31 (0.61%)	8 (0.15%)	60.8	70.9	65.6	10/28/2003	3:52pm - 4:52pm	65	8067 (97.36%)	180 (2.17%)	38 (0.45%)	53.7	70.2	59.4	65.6	57	8.6
SR51	B	6	08/12/2003	5:30pm - 6:30pm	65	6449 (98.69%)	73 (1.11%)	12 (0.18%)	56.9	73.8	63.0	11/06/2003	4:41pm - 5:41pm	65	7328 (98.65%)	86 (1.15%)	14 (0.18%)	53.3	71.7	60.8	63	60.2	2.8
SR51	B	7	08/12/2003	5:30pm - 6:30pm	65	6449 (98.69%)	73 (1.11%)	12 (0.18%)	57.5	68.0	62.4	09/18/2003	5:15pm - 6:15pm	65	8044 (98.89%)	77 (0.94%)	13 (0.15%)	52.5	78.9	58.8	62.4	57.9	4.5
SR51	B	8	08/12/2003	4:00pm - 5:00pm	65	8274 (97.68%)	160 (1.88%)	36 (0.42%)	56.9	69.6	62.8	09/18/2003	3:45pm - 4:45pm	65	8225 (97.62%)	168 (1.99%)	32 (0.37%)	51.6	69.5	58.6	62.8	58.6	4.2
SR51	B	9	08/12/2003	4:00pm - 5:00pm	65	8274 (97.68%)	160 (1.88%)	36 (0.42%)	52.0	71.6	57.4	A											
L101	C	1	08/20/2003	6:40am - 7:40am	65	8761 (95.46%)	170 (1.85%)	246 (2.68%)	60.2	72.6	64.3	11/18/2003	6:44am - 7:44am	63	9417 (95.36%)	226 (2.28%)	232 (2.34%)	57.2	72.4	62.5	64.3	62.2	2.1
L101	C	2	08/20/2003	8:00am - 9:00am	65	8761 (95.46%)	170 (1.85%)	246 (2.68%)	58.8	76.4	65.2	05/13/2004	8:06am - 9:06am	65	8715 (94.01%)	301 (3.24%)	254 (2074%)	53.5	75	63.4	65.2	63.2	2
L101	C	3	08/28/2003	8:04am - 9:04am	65	6226 (94.11%)	181 (2.73%)	208 (3.14%)	60.2	75.8	65.9	05/13/2004	8:03am - 9:03am	65	8001 (93.56%)	317 (3.71%)	233 (2.72%)	55.3	74.9	64.7	65.9	64.7	2.3
L101	C	4	08/21/2003	6:36am - 7:36am	65	7607 (95.14%)	142 (1.77%)	246 (3.07%)	57.7	66.2	62.2	05/13/2004	6:24am - 7:24am	65	8385 (94.37%)	198 (2.22%)	302 (3.39%)	50.7	63.8	55.8	62.2	55.2	7
L101	C	5	08/21/2003	7:55am - 8:55am	65	5201(92.75%)	163 (2.90%)	243 (4.33%)	58.6	69.6	63.2	11/19/2003	6:35am - 7:35am	65	7269 (93.03%)	233 (2.98%)	311 (3.98%)	57.7	72.6	64.5	63.2	63.1	0.1
L101	C	6	08/21/2003	7:55am - 8:55am	65	5201 (92.75%)	163 (2.90%)	243 (4.33%)	52.9	71.2	58.5	11/20/2003	7:58am - 8:58am	65	6289 (94.11%)	184 (2.75%)	209 (3.12%)	49.7	68	57.1	58.5	56.7	1.8
L101	C	7	08/21/2003	6:37am - 7:37am	65	7607 (95.14%)	142 (1.77%)	246 (3.07%)	61.4	76.0	67.7	11/19/2003	7:51am - 8:51am	63	7091 (93.70%)	221 (2.92%)	255 (3.36%)	55.7	70.3	60.5	67.7	60.6	7.1
L101	C	8	09/04/2003	6:30am - 7:30am	65	8926 (95.34%)	222 (2.37%)	214 (2.28%)	57.7	85.0	72.4	11/20/2003	6:32am - 7:32am	58	7071 (96.06%)	135 (1.83%)	155 (2.10%)	59.2	76.3	66.1	72.4	67.2	5.2
L101	C	9	09/04/2003	7:50am - 8:50am	65	8120 (94.19%)	240 (2.78%)	260 (3.01%)	64.2	77.7	69.6	11/25/2003	7:58am - 8:58am	65	8428 (95.05%)	218 (2.45%)	220 (2.48%)	61.9	77.1	69.1	69.6	69.1	0.5
L101	C	10	08/20/2003	6:40am - 7:40am	65	6840 (95.27%)	131 (1.82%)	208 (2.89%)	67.5	83.3	73.9	11/26/2003	6:28am - 7:28am	63	5590 (93.15%)	176 (2.93%)	235 (3.91%)	60.8	82.5	72.6	73.9	73	0.9
L101	D	1	09/30/2003	6:00am - 7:00am	65	8555 (94.32%)	323 (3.56%)	192 (2.11%)	58.5	68.5	61.9	01/28/2004	6:03am - 7:03am	65	9102 (95.52%)	343 (3.59%)	83 (0.87%)	50.5	66.7	55.7	61.9	55.8	6.1
L101	D	2	09/30/2003	6:00am - 7:00am	65	8555 (94.32%)	323 (3.56%)	192 (2.11%)	55.2	65.0	58.8	01/28/2004	6:02am - 7:02am	65	9102 (95.52%)	343 (3.59%)	83 (0.87%)	48.8	64.8	53.5	58.8	53.6	5.2
L101	D	3	10/02/2003	6:10am - 7:10am	65	8384 (94.97%)	276 (3.12%)	168 (1.90%)	61.8	69.9	64.7	01/01/2704	6:27am - 7:27am	65	9128 (94.83%)	391 (4.06%)	106 (1.10%)	55.5	64.7	59	64.7	58.8	5.9
L101	D	4	10/01/2003	6:02am - 7:02am	65	9835 (95.31%)	323 (3.13%)	160 (1.55%)	60.5	67.4	64.0	02/11/2004	6:00am - 7:00am	65	9319 (95.58%)	359 (3.68%)	71 (0.72%)	55	64	58.1	64	58.5	5.5
L101	D	5	10/08/2003	6:05am - 7:05am	65	8047 (94.52%)	345 (4.05%)	121 (1.42%)	55.1	75.7	59.3	02/11/2004	6:02am - 7:02am	65	9319 (95.58%)	359 (3.68%)	71 (0.72%)	52.3	60.3	55.9	59.3	55.5	3.8
L101	D	6	10/07/2003	6:10am - 7:10am	65	8794 (95.38%)	312 (3.38%)	113 (1.22%)	62.1	70.8	66.9	01/27/2004	6:24am - 7:24am	65	9128 (94.83%)	391 (4.06%)	106 (1.10%)	56.7	65.4	61.3	66.9	61.1	5.8
L101	D	7	10/07/2003	6:07am - 7:07am	65	7920 (95.03%)	244 (2.92%)	170 (2.03%)	58.9	71.8	64.4	01/28/2004	6:05am - 7:05am	65	9102 (95.52%)	343 (3.59%)	83 (0.87%)	52.3	70.6	57.2	64.4	56.9	7.5
L101	D	8	10/08/2003	6:00am - 7:00am	65	7761 (95.47%)	210 (2.58%)	158 (1.94%)	54.2	67.9	60.8	01/28/2004	6:02am - 7:02am	65	9102 (95.52%)	343 (3.59%)	83 (0.87%)	47	63.3	52.5	60.8	52	8.8
L202	E	1	10/09/2003	8:51am - 9:51am	65	2200 (92.12%)	89 (3.72%)	99 (4.14%)	56.6	69.1	63.1	12/03/2003	9:11am - 10:11am	65	2097 (92.66%)	75 (3.31%)	91 (4.02%)	46.8	66.2	54.2	63.1	54.5	8.6
L202	E	2	10/09/2003	10:23am - 11:23am	65	1830 (92.56%)	74 (3.74%)	73 (3.69%)	49.4	70.1	58.0	12/04/2003	9:47am - 10:47am	65	1908 (93.30%)	62 (3.03%)	75 (3.66%)	42.8	65.2	52.7	58	52.6	5.4
L202	E	3	10/09/2003	10:20am - 11:20am	65	1830 (92.56%)	74 (3.74%)	73 (3.69%)	50.2	69.0	57.9	12/04/2003	9:45am - 10:45am	65	1908 (93.30%)	62 (3.03%)	75 (3.66%)	43.1	63.6	51.4	57.9	51.9	6.6
L202	E	4	10/08/2003	2:08pm - 3:08pm	65	2764 (94.81%)	80 (2.74%)	71 (2.43%)	50.6	66.5	58.8	10/29/2003	1:46pm - 2:46pm	65	2659 (92.68%)	140 (4.87%)	70 (2.43%)	46.1	65.6	52.4	58.8	52.3	6.5
L202	E	5	10/09/2003	8:50am - 9:50am	65	2200 (92.12%)	89 (3.72%)	99 (4.14%)	53.2	72.6	60.5	12/03/2003	9:10am - 10:10am	65	2097 (92.66%)	75 (3.31%)	91 (4.02%)	43.6	74.3	57	60.5	57.3	3.2
L202	E	6	10/09/2003	8:52am - 9:52am	65	2200 (92.12%)	89 (3.72%)	99 (4.14%)	53.3	71.5	60.4	12/03/2003	9:10am - 10:10am	65	2097 (92.66%)	75 (3.31%)	91 (4.02%)	48.1	62.2	52.7	60.4	53	7.4

A - Post readings will be conducted in a later phase (contractor did not pave this section of freeway as originally intended)

ADOT Quiet Pavement Phase I

Pre and Post Overlay Readings

Site			Pre-Overlay Data		Weather Conditions				Noise Readings			Post-Overlay Data		Weather Conditions				Noise Readings			Readings with Traffic Adjustment: Leq with Adjustment		
Route	Segment	Receiver	Date	Time	Avg Temp. (°F)	Avg Wind Spd (mph)	Wind Direction	Avg Humidity (%)	Lmin	Lmax	Leq	Date	Time	Avg Temp. (°F)	Avg Wind Spd (mph)	Wind Direction	Avg Humidity (%)	Lmin	Lmax	Leq	Pre Leq	Post Leq	Reduction
L101	A	1	07/30/2003	11:45am - 12:45pm	94.0	1.1	Variable	37.6	62.7	81.5	74.6	11/06/2003	11:30am - 12:30pm	75.9	0.4	Northeast	15.1	60.2	81	69.8	74.6	69.3	5.3
L101	A	2	07/30/2003	11:45am - 12:45pm	92.0	1.4	Variable	40.6	60.0	72.2	64.3	01/29/2004	10:18am - 11:18am	59.7	1.0	Northeast	25.1	49.7	68.4	55.5	64.3	55.7	8.6
L101	A	3	07/30/2003	10:17am - 11:17am	92.9	1.2	Northeast	36.7	59.0	72.4	64.6	11/06/2003	10:00am - 11:00am	74.1	1.0	Northeast	18.4	52.1	69.5	59.7	64.6	58.5	6.1
L101	A	4	07/30/2003	10:15am - 11:15am	92.2	2.2	Variable	39.2	61.2	76.8	66.5	01/27/2004	10:13am - 11:13am					53.8	77.7	60.6	66.5	59.2	7.3
L101	A	5	08/05/2003	9:30am - 10:30am	96.0	2.8	Variable	20.0	50.3	69.9	55.6	01/28/2004	9:42am - 10:42am	59.8	1.7	Northeast	23.8	47.7	59.7	52.5	55.6	52.2	3.4
L101	A	6	07/29/2003	11:00am - 12:00pm	90.5	3.2	Variable	34.0	52.6	70.1	59.3	01/28/2004	11:07am - 12:07pm	71.9	1.3	Southeast	16.1	49.1	72.4	57	59.3	56.1	3.2
L101	A	7	08/05/2003	11:00am - 12:00pm	99.8	1.6	Southwest	16.0	51.1	75.9	60.7	10/29/2003	11:02am - 12:02pm	79.7	1.2	Southeast	17.7	47.5	76.7	58	60.7	58.4	2.3
L101	A	8	07/29/2003	11:05am - 12:05pm	97.7	2	Variable	32.3	56.7	78.6	64.9	10/29/2003	11:00am - 12:00pm	83.3	4.1	Southeast	20.0	51.2	73.3	59.5	64.9	59.1	5.8
L101	A	9	07/29/2003	9:30am - 10:30am	92.2	2.1	Variable	37.0	63.3	84.0	73.1	10/29/2003	9:30am - 10:30am	76.1	5.4	Variable	21.7	59.5	83.3	69.6	73.1	69.6	3.5
L101	A	10	07/29/2003	9:30am - 10:30am	94.6	1.6	Variable	36.9	63.2	79.9	69.0	10/29/2003	9:33am - 10:33am	76.7	3.1	Variable	21.3	58.4	78.6	65.5	69	65.5	3.5
L101	A	11	07/29/2003	9:30am - 10:30am	90.7	2.3	Variable	35.9	63.5	81.0	70.1	02/10/2004	10:27am - 11:27am	66.6	1.0	East	11.1	58.4	80.6	66.7	70.1	67.5	2.6
SR51	B	1	08/07/2003	4:00pm - 5:00pm	108.4	2.1	Variable	16.3	59.8	71.7	64.2												
SR51	B	2	08/07/2003	4:00pm - 5:00pm	108.4	2.1	Variable	16.3	60.7	76.9	66.3												
SR51	B	3	08/12/2003	4:00pm - 5:00pm	108.5	3.3	Northwest	16.6	63.9	73.1	68.4												
SR51	B	4	08/13/2003	4:00pm - 5:00pm	111	1.1	Variable	14.9	62.6	76.7	67.4	10/28/2003	5:15pm - 6:15pm	71	N/A	N/A	24.1	54.1	69.3	59.9	67.4	57.6	9.8
SR51	B	5	08/13/2003	5:30pm - 6:30pm	106.7	1.8	Variable	20.3	60.8	70.9	65.6	10/28/2003	3:52pm - 4:52pm	85	1.2	Variable	12.3	53.7	70.2	59.4	65.6	57	8.6
SR51	B	6	08/12/2003	5:30pm - 6:30pm	104.4	1.3	West	18.6	56.9	73.8	63.0	11/06/2003	4:41pm - 5:41pm	83	N/A	N/A	19.3	53.3	71.7	60.8	63	60.2	2.8
SR51	B	7	08/12/2003	5:30pm - 6:30pm	101.1	0.8	Variable	19.4	57.5	68.0	62.4	09/18/2003	5:15pm - 6:15pm	94.9	1.8	West	9.6	52.5	78.9	58.8	62.4	57.9	4.5
SR51	B	8	08/12/2003	4:00pm - 5:00pm	106.4	3.5	Variable	18	56.9	69.6	62.8	09/18/2003	3:45pm - 4:45pm	98.6	2.7	Variable	8.3	51.6	69.5	58.6	62.8	58.6	4.2
SR51	B	9	08/12/2003	4:00pm - 5:00pm	106.2	1.1	Variable	17	52.0	71.6	57.4												
L101	C	1	08/20/2003	6:40am - 7:40am	84.1	0.87	Southwest	57.7	60.2	72.6	64.3	11/18/2003	6:44am - 7:44am	54	N/A	N/A	61.9	57.2	72.4	62.5	64.3	62.2	2.1
L101	C	2	08/20/2003	8:00am - 9:00am	87.4	0.7	East	51.9	58.8	76.4	65.2	05/13/2004	8:06am - 9:06am	70	0.2	North	34.3	53.5	75	63.4	65.2	63.2	2
L101	C	3	08/28/2003	8:04am - 9:04am	85.0	0.9	Variable	61.1	60.2	75.8	65.9	05/13/2004	8:03am - 9:03am	65.3	0.2	Variable	25	55.3	74.9	64.7	65.9	64.7	2.3
L101	C	4	08/21/2003	6:36am - 7:36am	86.4	1.3	West	54.7	57.7	66.2	62.2	05/13/2004	6:24am - 7:24am	54.8	0.3	North	35.1	50.7	63.8	55.8	62.2	55.2	7
L101	C	5	08/21/2003	7:55am - 8:55am	88.5	1.1	Variable	14.9	58.6	69.6	63.2	11/19/2003	6:35am - 7:35am	65.6	1.5	Variable	29.4	57.7	72.6	64.5	63.2	63.1	0.1
L101	C	6	08/21/2003	7:55am - 8:55am	86.4	1.8	West	56.1	52.9	71.2	58.5	11/20/2003	7:58am - 8:58am	63.5	N/A	N/A	37.3	49.7	68	57.1	58.5	56.7	1.8
L101	C	7	08/21/2003	6:37am - 7:37am	93.5	1.3	Variable	62.9	61.4	76.0	67.7	11/19/2003	7:51am - 8:51am	59.5	1.1	Variable	36.4	55.7	70.3	60.5	67.7	60.6	7.1
L101	C	8	09/04/2003	6:30am - 7:30am	86	1.3	Variable	55.7	57.7	85.0	72.4	11/20/2003	6:32am - 7:32am	53.4	N/A	N/A	56.6	59.2	76.3	66.1	72.4	67.2	5.2
L101	C	9	09/04/2003	7:50am - 8:50am	91.3	2	Variable	44.3	64.2	77.7	69.6	11/25/2003	7:58am - 8:58am	55.8	1.6	Northwest	24.9	61.9	77.1	69.1	69.6	69.1	0.5
L101	C	10	08/20/2003	6:40am - 7:40am	84.5	1.1	Variable	57.3	67.5	83.3	73.9	11/26/2003	6:28am - 7:28am	44.8	0.4	Southwest	40.1	60.8	82.5	72.6	73.9	73	0.9
L101	D	1	09/30/2003	6:00am - 7:00am	72.3	Calm	Calm	51.1	58.5	68.5	61.9	01/28/2004	6:03am - 7:03am	42.1	0.3	West	83.9	50.5	66.7	55.7	61.9	55.8	6.1
L101	D	2	09/30/2003	6:00am - 7:00am	73.4	Calm	Calm	39	55.2	65.0	58.8	01/28/2004	6:02am - 7:02am	42.1	0.3	West	83.9	48.8	64.8	53.5	58.8	53.6	5.2
L101	D	3	10/02/2003	6:10am - 7:10am	74.6	Calm	Calm	48.9	61.8	69.9	64.7	01/01/2704	6:27am - 7:27am	34.3	Calm	Calm	88.4	55.5	64.7	59	64.7	58.8	5.9
L101	D	4	10/01/2003	6:02am - 7:02am	73	0.2	East	39.1	60.5	67.4	64.0	02/11/2004	6:00am - 7:00am	38.8	Calm	Calm	59.6	55	64	58.1	64	58.5	5.5
L101	D	5	10/08/2003	6:05am - 7:05am	64.1	Calm	Calm	71.1	55.1	75.7	59.3	02/11/2004	6:02am - 7:02am	38.8	Calm	Calm	59.6	52.3	60.3	55.9	59.3	55.5	3.8
L101	D	6	10/07/2003	6:10am - 7:10am	74.7	Calm	Calm	38	62.1	70.8	66.9	01/27/2004	6:24am - 7:24am	34.3	Calm	Calm	88.4	56.7	65.4	61.3	66.9	61.1	5.8
L101	D	7	10/07/2003	6:07am - 7:07am	75.3	Calm	Calm	42.9	58.9	71.8	64.4	01/28/2004	6:05am - 7:05am	42.1	0.3	West	83.9	52.3	70.6	57.2	64.4	56.9	7.5
L101	D	8	10/08/2003	6:00am - 7:00am	67.7	0.2	West	68.4	54.2	67.9	60.8	01/28/2004	6:02am - 7:02am	42.1	0.3	West	83.9	47	63.3	52.5	60.8	52	8.8
L202	E	1	10/09/2003	8:51am - 9:51am	84.3	4.4	Variable	29.4	56.6	69.1	63.1	12/03/2003	9:11am - 10:11am	60.0	0.7	East	28.4	46.8	66.2	54.2	63.1	54.5	8.6
L202	E	2	10/09/2003	10:23am - 11:23am	92.3	2.1	Variable	24.6	49.4	70.1	58.0	12/04/2003	9:47am - 10:47am	65.9	3.7	Northeast	19	42.8	65.2	52.7	58	52.6	5.4
L202	E	3	10/09/2003	10:20am - 11:20am	92.3	2.1	Variable	24.6	50.2	69.0	57.9	12/04/2003	9:45am - 10:45am	65.9	3.7	Northeast	19	43.1	63.6	51.4	57.9	51.9	6.6
L202	E	4	10/08/2003	2:08pm - 3:08pm	92.3	1.5	South	28.1	50.6	66.5	58.8	10/29/2003	1:46pm - 2:46pm	88.3	1.6	Variable	13	46.1	65.6	52.4	58.8	52.3	6.5
L202	E	5	10/09/2003	8:50am - 9:50am	84.3	4.4	Variable	29.4	53.2	72.6	60.5	12/03/2003	9:10am - 10:10am	60.0	0.7	East	28.4	43.6	74.3	57	60.5	57.3	3.2
L202	E	6	10/09/2003	8:52am - 9:52am	84.3	4.4	Variable	29.4	53.3	71.5	60.4	12/03/2003	9:10am - 10:10am	60.0	0.7	East	28.4	48.1	62.2	52.7	60.4	53	7.4

A - Post readings will be conducted in a later phase (contractor did not pave this section of freeway as originally intended)

Site Characteristics				
	Noise Wall Present	Freeway Elevated	Freeway Depressed	Notes
L101-A-1	Yes	Yes	No	Retaining wall, open space area
L101-A-2	No	No	No	Behind 5' privacy wall, removed at least 500' from freeway. Flyovers to SR51 withni monitoring area.
L101-A-3	No	Yes	No	5' decorative wall
L101-A-4	Yes	Yes	No	Front yard of resident facing freeway.
L101-A-5	Yes	Yes	No	Coyote Basin Park at picnic area.
L101-A-6	Yes	Yes	No	Behind privacy wall.
L101-A-7	Yes*	Yes	No	*Noise wall does not go above grade of freeway, acts as a retaining wall.
L101-A-8	No	No	Yes	Behind 6' privacy wall in cul-de-sac. Frontage road between site and freeway.
L101-A-9	No	No	No	Frontage road.
L101-A-10	Yes	No	Yes	Frontage road.
L101-A-11	No	No	Yes	Frontage road, reading taken in residents front yard facing freeway.
SR51-B-1	Yes	No	Yes	
SR51-B-2	Yes	No	Yes	Park (get Name)
SR51-B-3	Yes	No	Yes	
SR51-B-4	Yes	No	Yes	
SR51-B-5	Yes	No	Yes	
SR51-B-6	No	No	Yes	Earthen Berm
SR51-B-7	No	No	Yes	Earthen Berm
SR51-B-8	No	Yes	No	Freeway slightly elevated from grade at Park. Reading taken at south end of wall (wall ends prior to reading location).
SR51-B-9	Yes	No	No	Large retention area between freeway and noise wall.
L101-C-1	Yes	No	No	
L101-C-2	Yes	No	Yes	
L101-C-3	No	No	Yes	

L101-C-4	No	No	Yes	
L101-C-5	Yes	Yes	No	Reading taken in neigborhood park.
L101-C-6	Yes	Yes	No	
L101-C-7	No	No	Yes	
L101-C-8	No	Yes	No	
L101-C-9	No	No	No	
L101-C-10				
L101-D-1	Yes	No	Yes	
L101-D-2	Yes	No	Yes	
L101-D-3	Yes	No	Yes	
L101-D-4	Yes	No	Yes	
L101-D-5	Yes	No	Yes	
L101-D-6	Yes	No	Yes	
L101-D-7	No	No	Yes	Frontage road. Privacy wall between frontage road and freeway.
L101-D-8	Yes	No	No	Cul-de-sac, privacy wall.
L202-E-1				
L202-E-2				
L202-E-3				
L202-E-4				
L202-E-5				
L202-E-6				